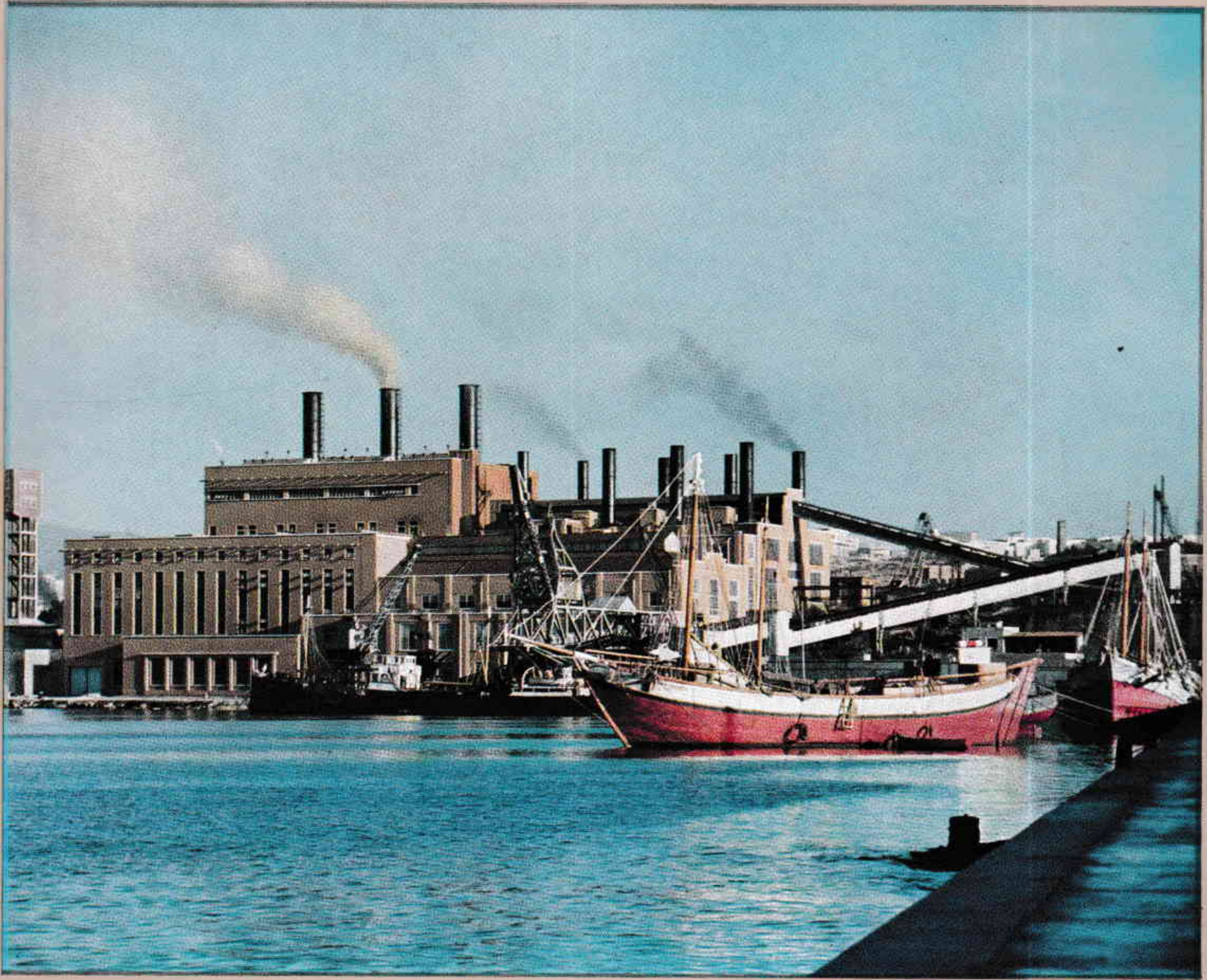

Present Trends in Large Power Station Auxiliaries and their Electrical Equipment

'ENGLISH ELECTRIC'

Present Trends in Large Power Station Auxiliaries and their Electrical Equipment

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In 1944 *The English Electric Company decided to set up a committee of representatives from its Liverpool and Stafford Works to investigate the present and future requirements of power station auxiliary electrical systems and equipment. The committee, under the chairmanship of Mr. W. E. Streete, A.R.Ae.S., Assoc.I.E.E., of the Commercial Manager's Office, Stafford, found it convenient as its work progressed to add other representatives from the Company's London Branch, the General Engineering Projects Department and the Atomic Power Division. The purpose of this investigation has been to ensure that suitable machines and electrical equipment are made available to meet the needs of progressively larger boilers and turbines. The committee has issued several reports which have been circulated to certain overseas territories, and as a result of the interest shown, particularly in Australia, the following article has been prepared.*

THE DEMAND FOR larger and larger generating units has been created by the trend towards large interconnected power supply systems, the economic advantages of which have become better understood. At present steam turbo-alternator units up to 550 MW are being built in the United Kingdom, and future 700 or 800 MW units are under consideration.

Progress in steam turbo-alternator design has been made possible chiefly by thermal and mechanical improvements enabling higher steam pressures and temperatures to be used in the turbine, resulting in rapid increases in rating and a better heat rate.

Similarly, the alternator cooling system particularly has undergone major changes, resulting in a considerable increase of rating within a given frame size and weight. The progress in turbo-alternator design has been matched by boiler manufacturers in producing high capacity steam generating units.

In the United States, development is well ahead with supercritical pressure cycles up to 5,000 p.s.i.g. and temperatures of 1,200°F. The general level of the steam conditions, however, is showing signs of stabilising around 2,300 p.s.i.g., 1,050/1,050°F single reheat. These advanced steam conditions obviously imply wide modifications to conventional auxiliaries systems, as considerably larger individual as well as total auxiliaries loads have to be accommodated. The tremendous changes in unit ratings and thermal characteristics over the last few decades are illustrated in Figs. 1 and 2.

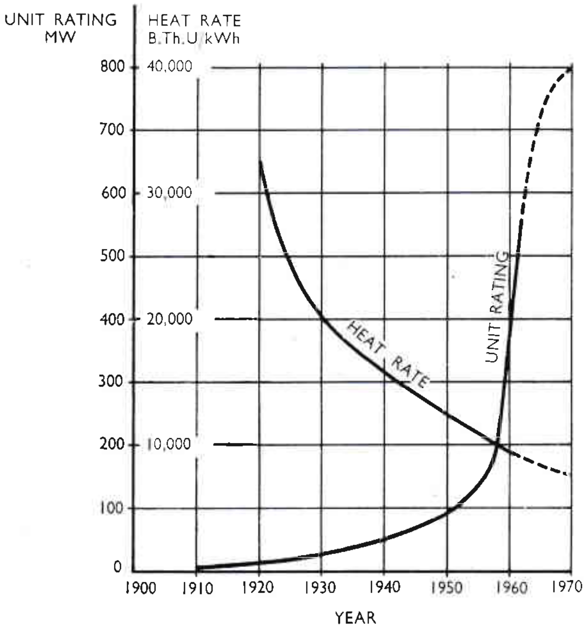


Fig. 1.—Progress in unit ratings and heat rate

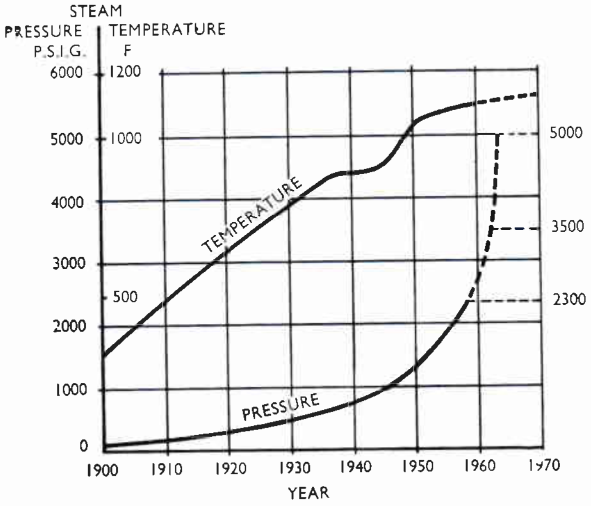


Fig. 2.—Progress in steam conditions

The advent of nuclear power stations, although presenting numerous problems regarding auxiliaries for reactors, has actually caused reversion to lower steam conditions and ratings of turbo-alternators associated with this plant, at least for the time being. There is little doubt however that progress will result in more advanced steam conditions, with consequent increases in the ratings of reactor and generating units.

The purpose of this article is to re-examine the established practice in auxiliaries systems in the light of present-day developments. To limit the scope of the article, only power stations with generating units of 200 MW and above have been considered, with some references to lower ratings.

REQUIREMENTS FOR AUXILIARIES

The auxiliaries for a power station should provide an economic degree of reliability combined with high efficiency as well as ease of operation and maintenance. The degree of reliability should be considered in relation to the financial risk of forced outage or damage to the plant. Such evaluation can be carried out accurately only if adequate statistical information on plant operation is available. Even then the figures obtained should be considered in the light of experience in power station operation.

An analysis of auxiliaries load shows that this is concentrated in a few auxiliaries which take about 70% of the power: these include boiler feed pumps, boiler fans and circulating water pumps. The remaining auxiliaries consist of a large number of smaller drives and consequently present no problems. It is therefore obvious that the large auxiliaries are establishing the general pattern to be adopted. In this section a brief survey is made of present-day practice and future trends regarding these auxiliaries.

Boiler Feed Pumps

The capacity of boiler feed pumps is proportional to the steam consumption of the main plant and to the total head required. In practice a margin is necessary to make allowance for make-up water, soot blowing, boiler blow-down, and increased boiler pressure to the safety valve blow-out setting. A further margin is usually included to allow for working at reduced electrical supply frequency and for reduced efficiency of the pump within its lifetime. These margins together constitute about 15% of the pump motor rating. During normal operating conditions, and particularly when the unit operates at part load, the excess quantity and head have to be dissipated by one means or another.

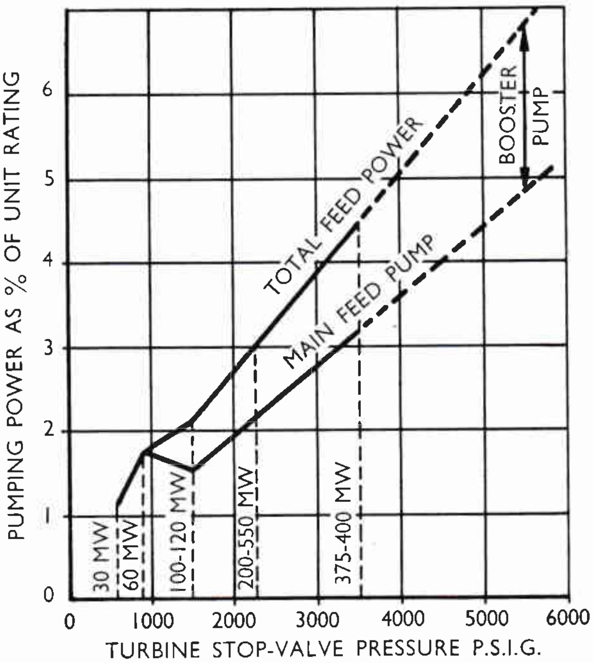


Fig. 3.—Approximate boiler feed pumping power requirements

The feed pump constitutes an appreciable portion of the auxiliaries load, particularly for the larger units operating at advanced steam conditions, as can be seen from Fig. 3. Furthermore, at pressures above 1,000 p.s.i.g. the single-feed-pump arrangement is becoming less economical due to increased cost of feed heaters which have to be designed for full pump discharge pressure. It is therefore a general practice to provide a split-feed-pump arrangement for units of 100 MW and above operating at advanced steam conditions.

The increasing rating of feed pumps associated with larger units presents two major problems. The first is the selection of the most economical and reliable drive, and the other is associated with the high losses due to dissipation of head when the pump is operating below design duty. Both problems have a bearing on the design of the auxiliaries supply system if motor drive is selected.

For unit ratings up to 200 MW, drives for main feed pumps by squirrel cage motors have been generally accepted, the standby pump being either separate-turbine or electrically driven. For machines rated 275 MW and above, a number of drives are open for consideration, namely:—

(*a*) Main pump driven from main generator shaft through variable speed coupling, and electrically driven standby pumps, the booster pump being either electrically or shaft driven.

(*b*) Separate-turbine driven main pump and electrically driven standby and booster pumps.

(*c*) All pumps electrically driven by squirrel cage motors.

(*d*) Main pumps electrically driven by slipring motors with speed control. The booster and standby pumps driven by squirrel cage motors.

In the first two arrangements the burden on the auxiliaries supply is greatly eased, as provision is necessary only for 50% duty standby feed pumps and the booster pumps. An economical comparison between these two arrangements shows that generator shaft drive is cheaper than separate turbine drive. The principal disadvantage of the generator shaft drive is the reliance on large variable-speed fluid couplings, of which operating experience at present is limited. Another point is the complication at the generator end to accommodate the feed pump and exciter.

Arrangement (*c*) with the squirrel cage motor drive for main feed pumps (Fig. 4) has the attraction of greater reliability and less maintenance. However, due to the increased losses in head dissipation in the feed regulator, and associated erosion of the valve, the general trend is towards some form of economical variable-speed drive. The large slipring motors recently available for 3,000 or 3,600 r.p.m. operation will no doubt influence this trend considerably. The analysis of pump characteristics for a 275 MW unit shows that the range of speed control required is approximately 8% for full load operation, with a maximum of 13·5% from no

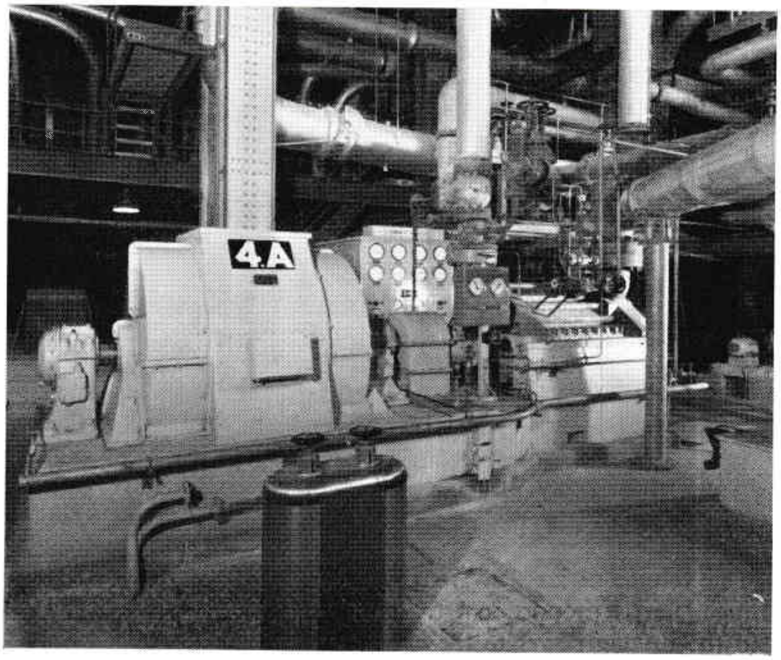


Fig. 4.—Boiler feed pump driven by 2,070 h.p. 2,950 r.p.m. 3·3 kV squirrel cage motor with closed-air-circuit and water cooling

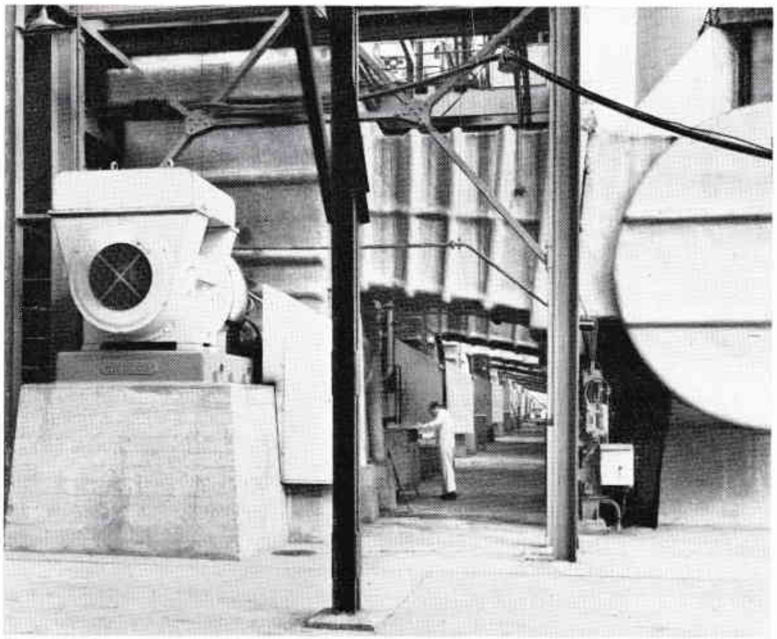


Fig. 5.—Induced draught fan driven by 388 *h.p.* 740 *r.p.m.* 3·3 *kV squirrel cage weatherproof motor with closed-air-circuit air cooling*

load to full load. This small range of control can easily be obtained by available equipment.

The availability of feed supply to the boilers is extremely critical, as its failure may result in considerable and costly damage to the boiler plant. It is therefore an established practice to provide standby feed pumps arranged for automatic starting. For the smaller generating units one standby pump, either electrically or steam driven, may be used for a number of units ; however, for the larger units this is not practicable and individual standby is provided. This usually consists of two 50% duty pumps with their motors connected to the station supply. Squirrel cage motor drive for the standby pumps is the most favoured because of its simplicity and high degree of availability as well as its quick starting characteristic.

Boiler Fans

The volume of air delivered by a centrifugal fan is proportional to its speed, and the driving power to the cube of the speed. On the other hand, the control of air flow of a constant-speed fan necessitates throttling by inlet vanes or dampers, both of which are inherently wasteful. Furthermore, the induced draught fans are subjected to erosion by the hot flue gases, and the rate of erosion increases approximately with the third power of the speed. It is therefore logical to control the fan output by a variable-speed drive. Such drives are however more expensive and their reliability compares less favourably with that of a robust directly coupled squirrel cage motor (Fig. 5).

Due to its inherent reliability the two-speed squirrel cage motor is a favoured arrangement for the larger units, with inlet vane air flow control. Often the lower speed is chosen to provide sufficient air flow for boiler operation at the normal full load condition, without allowance

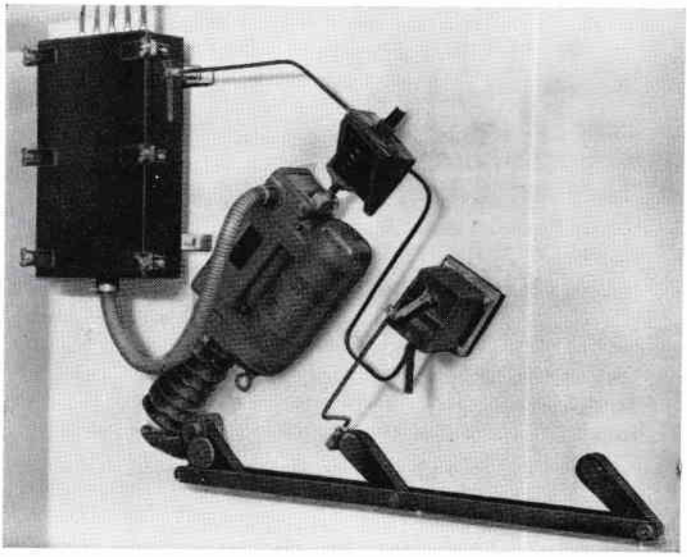


Fig. 6.—*'English Electric' boiler damper actuator Type* 291 *and position transmitter at Keadby power station* for operational margins and assuming a clean boiler with fuel at normal calorific value. The higher speed is called for only when the boiler is operating at conditions outside the normal design duty.

In assessing the rating of fans, allowance is made for fouling of boiler and flue ducts, as well as increased volume handled by induced draught fans with rise of flue gases temperature. In addition, a margin is allowed for reduction in the efficiency of the fan during its lifetime. All these margins combined increase the installed fan power above normal operating requirements by about 20-30% for forced draught fans and 30-60% for induced draught fans. It is questionable whether computation of all abnormal conditions occurring simultaneously is justified, and greater care in assessing the ratings of fans and drives would no doubt contribute to increased efficiency of the station.

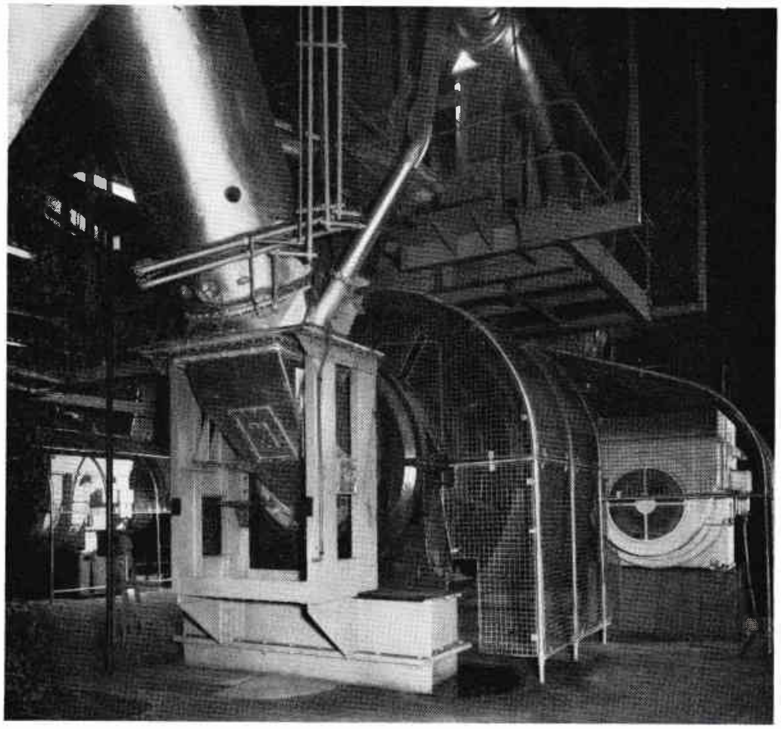


Fig. 7.—Pulverised fuel mill driven by 515 *h.p.* 590 *r.p.m.* 3·3 *kV high-torque squirrel cage motor with closed-air-circuit air cooling*

The arrangement of fans varies considerably for different boiler designs. For the smaller units up to 60 MW, single 100% duty fans are common. For larger units, two for 50% duty are preferable on account of fan design considerations and increased operating flexibility, and for very large units with multi-furnace boilers the number of fans will increase accordingly.

It is necessary to establish roughly the total power requirements for fans in the early stage of power station design, and these can be taken as about 0·5% of unit rating for the forced draught fans and 0·8% for the induced draught fans.

Pulverising Mills

The number of pulverising mills varies with the boiler design and type of coal, but four or six mills per boiler is a popular arrangement for small and medium size units. For very large units of 550 MW and 800 MW an increase in the number and size of pulverisers is necessary. For the smaller stations a centralised pulverising system is sometimes used, but for the larger stations the unit arrangement has a number of advantages on account of lower capital cost, simpler layout and operation.

As a first approximation it can be taken that the total power required by these mills is about 0·5% of unit rating, this being without any allowance for standby capacity.

Circulating Water Pumps

The circulating water arrangement may be of the cooling tower type, river type, or a mixed system. Generally, the river system requires less power on account of the smaller quantities of water needed due to a lower intake water temperature ; also the effective head in the river system is reduced if syphonic action in the water discharge is provided.

The centralised station system with one or two main discharge headers is the practice usually adopted, but for the larger generating stations the circulating water pumps are associated with the units. Standby pumps are sometimes provided, with their motors connected to the station supply. The trend is however to dispense with standby pumps and instead to increase the capacity of the unit pumps in such a way that on failure of one pump, the remaining pumps can cope with the total water requirements of all units. Sometimes this increased capacity is calculated to allow for normal vacuum to be maintained at station full load only in winter time. This means that reduced efficiency is accepted should failure of one pump occur in summer with the station operating at full load.

The power requirements for circulating water vary considerably with the site conditions and the system adopted, but close figures are available at an early stage of power station design. A provisional assessment of 0·3-0·6% of unit output can be taken for a station using river-water cooling and 0·5-1·0% for a cooling tower station. The higher figures refer to the smaller units while the lower figures are associated with large units operating at advanced steam conditions.

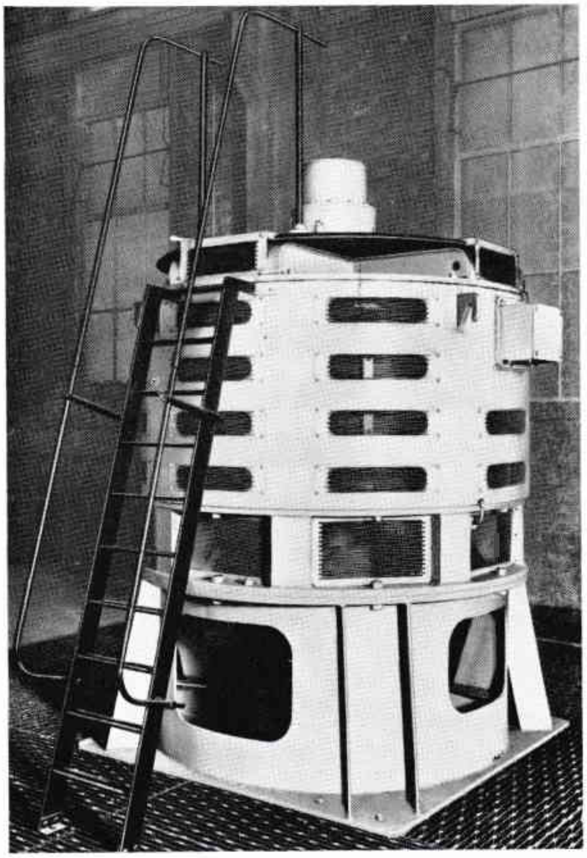


Fig. 8.—Vertical spindle squirrel cage motor, 1,180 *h.p.* 425 *r.p.m.* 3 *kV, driving circulating water pump*

Condensate Extraction

The condensate extraction pumps do not present any special problems of either a mechanical or electrical nature. A high degree of reliability of extraction is however necessary to prevent dangerous conditions which may arise if the water level in the condenser rises above a safe limit. For this reason it is the usual practice to provide two 100% duty pumps for each unit. The standby pump, however, is started manually on receiving the alarm that the main pump has failed.

For generating units with a reheat cycle it may be necessary to dump the steam in the condenser during emergency shut-down to avoid damage to superheaters, and this must be provided for with supercritical steam pressure turbines. The availability of the standby extraction pump under these conditions is of the utmost importance, and automatic starting from an independent supply is necessary.

Other Auxiliaries

The auxiliaries which have been described constitute the largest single items associated with the unit. The remaining numerous unit auxiliaries require comparatively small driving power individually, and consequently do not present particular problems in power station design. Their importance and reliability cannot be neglected however, as failure of some of them may affect the continuity of operation of the boiler plant, generating unit or the step-up transformer.

Two groups of auxiliaries require more specific attention in a coal fired station. These are coal and ash handling plant drives which contribute appreciably to the auxiliaries power demand. The arrangement for this plant is dependent on the type of fuel, site conditions and method of firing. While it is not possible to quote general figures, 0·3-0·5% of unit rating can be taken for a preliminary assessment of the combined load for both plants, the lower figure being applicable to the larger stations.

The excitation is generally provided by shaft-driven exciters although in some instances separately driven exciters have been provided for large units. With increasing turbo-alternator ratings the d.c. exciter becomes large, and serious consideration has been given to shaft-driven a.c. exciters with rectifying equipment. For a cross-compound unit a standby separately driven exciter is necessary for starting-up purposes. When the unit is up to speed the excitation is changed over to the shaft-driven exciter on each generator.

REQUIREMENTS FOR AUXILIARIES SUPPLY

The power requirements for steam power plant auxiliaries are determined by a number of factors, the chief of which are : unit rating, heat cycle, circulating water arrangement, type and handling of fuel, and ash disposal. These factors are established at an early stage of design as they form the fundamental parameters of the station. A preliminary assessment of the power required can therefore be made at an early date, thus enabling a decision to be reached on the auxiliaries system to be adopted.

The auxiliaries can be grouped broadly as (1) unit auxiliaries, i.e. those associated directly with the generating unit, and (2) station auxiliaries, i.e. general station services which include also provision for starting and emergency or standby supply. Table I shows typical auxiliaries loads as a percentage of unit rating. The figures are average and indicate the total capacity of running auxiliaries, that is excluding standbys.

For the reasons mentioned in the previous section it is necessary to include a margin in ratings of power station auxiliaries, and consequently most auxiliary motors run at less than full load when the station is operating at full load under normal conditions. A load factor is thus obtained which reduces the actual maximum demand to approximately 70-80% of the running installed power for the auxiliaries.

Unit Supply

Over the last decade the idea of unit power generation has been widely accepted and its advantages appear to be even more attractive for the larger units being installed at present and planned for the future. The unit auxiliaries system asso-

TABLE 1

TYPICAL AUXILIARIES LOADS AS A PERCENTAGE OF UNIT RATING

Unit		Percentage of Unit MW Rating							
Rating MW	Steam Condition	Boiler feed	Circul. water	Boiler auxil.	Turbo-alt. auxil.	Coal and ash	Station services	Total	
								Unit	Station
30	600 p.s.i.g. 850°F	1·2	1·0–1·5	4	0·5	0·5	0·5	6·7–7·2	1·0
60	900 p.s.i.g. 900°F	1·8	0·6–1·0	3·8	0·3	0·5	0·4	6·5–6·9	0·9
100	1,500 p.s.i.g. 1,050°F	2·2	0·5–0·7	3·5	0·3	0·4	0·3	6·5–6·7	0·7
120	1,500 p.s.i.g. 1,050/1,000°F	2·2	0·5–0·7	3·5	0·3	0·4	0·3	6·5–6·7	0·7
200	2,350 p.s.i.g. 1,050/1,000°F	3	0·3–0·5	3·3	0·2	0·4	0·25	6·8–7·0	0·65
275	2,300 p.s.i.g. 1,050/1,000°F	3	0·3–0·5	3·3	0·2	0·4	0·2	6·8–7·0	0·6
300	2,300 p.s.i.g. 1,050/1,000°F	3	0·3–0·5	3·2	0·2	0·4	0·2	6·7–6·9	0·6
550	2,300 p.s.i.g. 1,050/1,050°F	3	0·3–0·5	3·2	0·2	0·3	0·2	6·7–6·9	0·5
800	2,300 p.s.i.g. 1,050/1,050°F	3	0·3–0·5	3·2	0·2	0·3	0·1	6·7–6·9	0·4
375	3,500 p.s.i.g. 1,100/1,050/1,050°F	4·4	0·2–0·4	3·2	0·2	0·3	0·2	8·0–8·2	0·5

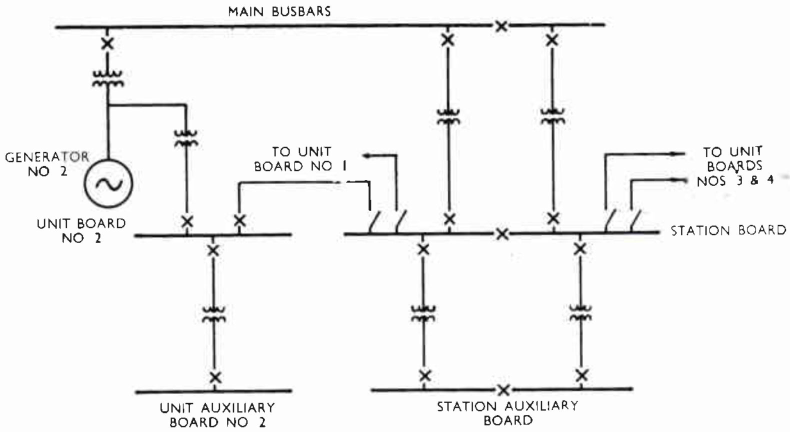


Fig. 9.—Basic arrangement of unit auxiliaries system

ciated with unit generation is based on two independent sources of supply, one derived from the generating unit and supplying the unit auxiliaries, and the other from the station busbars and supplying station services as well as providing standby for the unit auxiliaries. A typical arrangement is shown in Fig. 9.

The unit supply derived through a unit transformer connected directly to the generator has proved to be reliable and economical. It is true to say however that unit transformer supply is susceptible to disturbances during severe faults on the main system, but the system disturbances are somewhat cushioned by the impedance of the generator transformer. Furthermore, with the application of high-speed protection, and the ability of the modern motor to recover its speed after a momentary voltage drop, the unit transformer has held its position.

The rating of the unit transformer is usually based on the total connected capacity of running unit auxiliaries, i.e. excluding the standby drives. Accordingly the transformer is operating at about 75% full load throughout most of its life. The additional capacity is justified however on account of the extremely high reliability required of the auxiliaries system. Moreover, the spare capacity is available to maintain full output during abnormal conditions. Fig. 10 shows typical relative ratings of a unit transformer and a generator unit operating at sub-critical pressures.

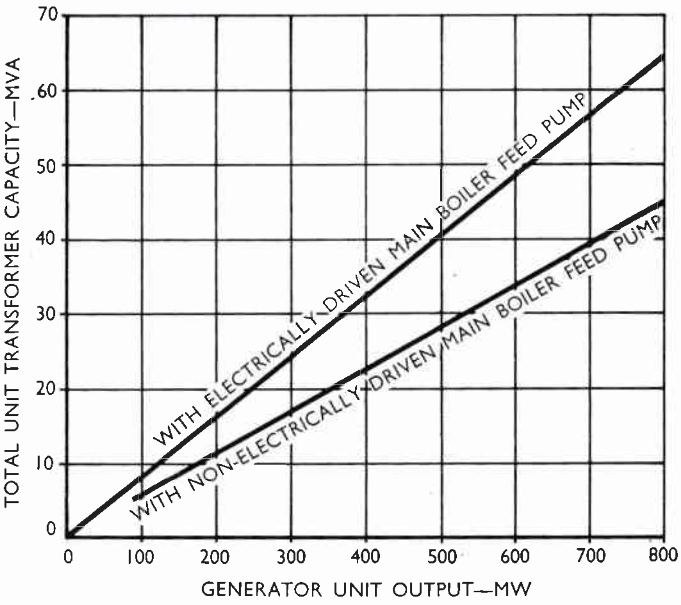


Fig. 10.—Typical unit transformer capacities for units operating at sub-critical pressures

Up to about 300 MW unit rating, operating at sub-critical pressures, the straight unit scheme as shown in Fig. 9 can be applied, with some qualifications. Above 300 MW the ratings of the unit and station transformers are inconveniently high, particularly with electrically driven boiler feed pumps. One solution to this problem is the division of unit auxiliaries into two or more sections, each section being fed either through two half-size unit transformers or one double-secondary transformer. The basic arrangement is shown in Fig. 11. This arrangement involves two or more operations to change over from station to unit supply and *vice versa*, depending on the number of sections introduced. This complicates slightly the procedure when starting-up and shutting-down the units, but is, in the author's opinion, of minor significance.

For the cross-compound generating units the

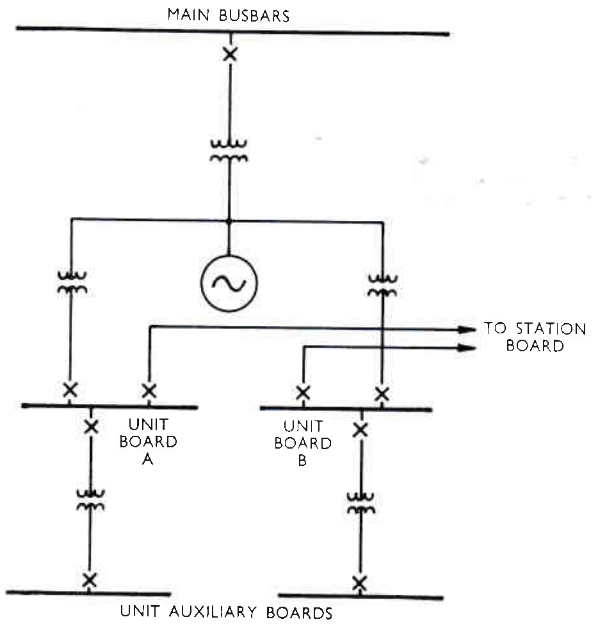


Fig. 11.—Basic arrangement for sectionalised unit auxiliaries

sectionalisation can be carried out by connecting one (or more) unit transformers to the terminals of each of the two generators, as indicated in Fig. 12. Such an arrangement introduces a small out-of-balance, depending on the condition of the auxiliaries load, but this should have no operational significance.

For large generating units operating at high steam pressures the method of driving the boiler feed pumps is the main consideration. As can be seen from Table I, the feed power demand for a steam pressure of 2,300 p.s.i.g. is about 50% of the total auxiliaries load, and even higher for 3,500 p.s.i.g. If therefore non-electric drive for the main feed pump is selected the capacity required for the unit transformer is correspondingly reduced, as illustrated in Fig. 10.

Station Supply

For unit type stations a supply independent of the individual units is necessary and the station supply must be available when all units are shut down. As large stations usually operate in interconnected systems the simplest method is to derive this supply from the main busbars through step-down transformers. For stations which are intended for operation in isolated systems an additional starting supply is necessary in the form of a self-contained house set.

The station supply is therefore obtained by either one or two station transformers feeding a station switchboard. Two 100% duty transformers are usually provided for stations with more than two units. The extra cost of the second transformer and associated switchgear may however be justified for a single or two unit station if an extremely high degree of availability is required.

The station supply should have sufficient capacity to meet the following load conditions simultaneously :—

(*a*) All running auxiliaries for station services at full station load.

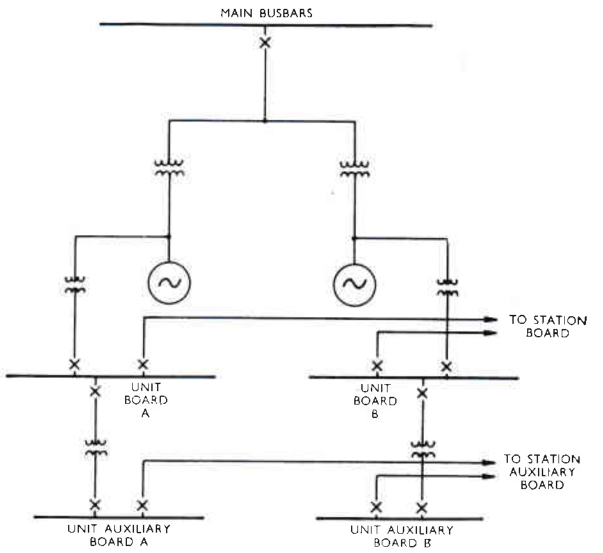


Fig. 12.—Basic arrangement for cross-compound unit auxiliaries

(*b*) The running auxiliaries of one unit operating at full load.

(*c*) The auxiliaries load for starting one or more units simultaneously.

For stations with comparatively small units the rating of the station transformer is not very critical and a commonly used rating in many new stations is 1·5 times that of the unit transformer. For large units however, every effort is made to reduce the standby capacity. Typical ratios of station to unit transformer ratings are given in Table II. These are based on the foregoing considerations and for various numbers of units in the station.

TABLE II

TYPICAL LOAD REQUIREMENTS FOR STATION TRANSFORMERS

Number of units	Number of station transformers	Simultaneous loads (defined in text)	Station/ Unit* load ratio
1	1	(a)+(b)	1·0
2	1	(a)+(b)+(c)	1·5
2	2	(b)	1·0
More than 2	2	(b)+(c)	1·3

* Unit load including boiler feed pumping power.

It should be noted that for single unit stations the unit transformer rating must be increased to provide also for station services in the event of failure of the station supply. In such stations therefore the unit and station transformers are of the same rating.

The load for station services depends on the ultimate number of units, type of fuel and associated handling plant. Typical figures for coal fired stations are given in Table I. About half these values is required for oil fired stations.

Selection of Voltage

For generating units up to about 100 MW a two-voltage system using 3·3 kV and 415 V has been generally adopted in Great Britain. For larger units however, with increased auxiliaries demand, the fault level and current rating are limiting factors in the economical design and manufacture of 3·3 kV switchgear. Furthermore, the voltage regulation and copper losses of the system become embarrassingly high.

For these larger units it is therefore desirable to raise the distribution voltage, and in Britain 6·6 kV is being used for 120 MW and 200 MW units operating at 2,300 p.s.i.g., and 11 kV for larger units. However, with increased unit ratings, difficulties are encountered on the low voltage switchgear of the auxiliaries system due to fault level, which becomes the limiting factor. With a three-voltage system many of the difficulties can be obviated while the simplicity of a straight unit system can be retained for still larger unit ratings, and in certain instances some easement can be obtained by the use of 550 V instead of the standard voltage of about 400 more generally employed.

The voltage drop on starting the auxiliaries does not normally present special problems except in the case of the boiler feed pumps. The feed pump motor is generally much larger than any other auxiliary and although starting current is restricted, it is of sufficient magnitude to cause a considerable dip in the supply voltage when the motor is switched on.

In order to ensure satisfactory starting, feed pump motors are designed to have sufficient accelerating torque with voltage down to 80% of the normal value.

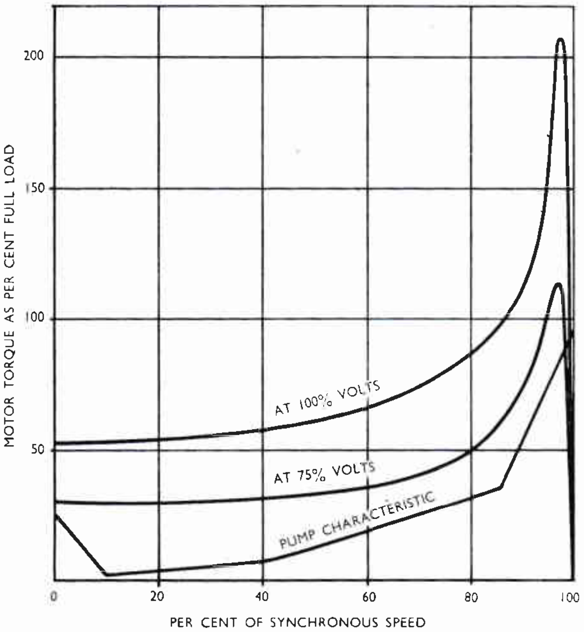


Fig. 13.—*Typical torque-speed characteristics of a* 6,200 *h.p.* 3,000 *r.p.m. feed pump motor*

All essential auxiliaries motors for British power stations are now designed to operate for 10 minutes at 75% of normal voltage. A typical characteristic of motor torque in relation to speed at 100% and 75% voltage is shown in Fig. 13.

It is apparent that some voltage adjustment is useful at the transformers and it is the usual practice to provide off-circuit tappings of ±2·5 and ±5% on unit and station transformers. When the main system voltage fluctuation is wide the station transformers are provided with on-load tap-changers. The ratio of the transformers at neutral tap position should be selected to provide near nominal system voltage at normal load. This is obtained closely enough if the ratio is based on 75% load at 0·8 power factor.

Fault Level

The voltage selected for an auxiliaries system is closely associated with the fault level, and both have to be considered in order to determine the most economical arrangement, the next higher standard voltage being adopted when the rating limit of available switchgear of a given voltage is reached.

It is desirable to have means of paralleling the station transformers (where two are provided) for change-over purposes, and the paralleled condition therefore establishes the maximum fault level on the station board. On the unit board the highest fault level which need be considered occurs when one station transformer and one unit transformer are paralleled. Provision for this condition appears to be satisfactory, although interlocks are necessary to prevent paralleling both station transformers with a unit transformer. On this basis it may be justifiable in some instances to provide unit switchgear for a lower fault level than that on the station board.

The breaking-capacity of unit switchgear could be further reduced if it would not be required to deal with the fault level during the brief period of paralleling the unit and station transformers. Reactors inserted between the paralleled supplies may be an economical proposition if the fault level during the transition period exceeds the rating of the switchgear by an amount of up to 20-30%.

The induction motors contribute a fault current of short duration due to the effect of residual magnetism. This current approaches the motor starting current at full voltage and decays within a few cycles. This contribution for a 200 MW unit with a total motor load on the unit board of 14,000 h.p. (13 MVA) amounts to approximately 13 × 5 = 65 MVA. It is therefore advisable to take this into consideration when calculating the fault level of the auxiliaries system.

Earthing

Opinions on the type of earthing for auxiliaries systems vary considerably, but the main differences are centred on the question of whether an earth fault should cause immediate tripping of the affected circuit or should initiate an alarm. It is argued that in the latter case the affected circuit can remain in service until alternative arrangements for the supply can be made at a convenient time.

Solid or resistance earthing is therefore provided when immediate tripping is accepted. With solid earthing the system voltage surges are lowest, while with resistance earthing, earth fault current can be reduced to a comparatively small value. Voltage-transformer earthing with an alarm reduces the unexpected outages, but equipment so earthed may be subjected to severe voltage surges, with possibility of insulation weakening.

The present trend appears to be the choice between solid earthing and voltage-transformer earthing, depending on the operating mode required. The extra cost of resistance earthing and the additional accommodation necessary are not really justified, particularly for transformer ratings and voltage levels in large stations.

For the main earth connection present practice appears to favour one common station earthing system. To this system are connected all neutrals, structures, tanks, switchgear, motor enclosures and cable sheaths. Thus the whole station forms an equipotential area within which the voltage gradients are reduced to minimum under all fault conditions.

The earth connections are usually made of bare copper strips which are fixed in trenches or along the cable supports, and solidly connected to the main earthing ring. For connections laid direct in the ground some bituminous or plastic serving is recommended as protection against corrosion. The cross-section of the copper strip can be chosen on the basis of a temperature rise of 400°C after 3 seconds, and this gives a current rating of approximately 80,000 amp/sq in. The minimum section however should not be less than 1 in. × $\frac{1}{8}$ in. on account of mechanical damage.

The lead sheath and armour of cables are solidly bonded to the body of the terminating equipment which in turn is bonded to the main station earth. Small distribution and terminal boxes and small motors up to about 100 h.p. can be earthed through the armour and sheath of the cable. In the case of single core cables it is necessary to bond the sheaths together and this is usually done by plumbing a width of lead sheathing round the individual sheaths of the three-phase group. For a long run of a three-phase group, intermediate bonding is provided for about every 50 yards of run to keep the sheath voltage rise within reasonable limits under short-circuit conditions.

Auxiliaries Control

The trend towards increased centralisation of controls, and to a certain degree of automation, is evident in modern power plant. This is due to the small operating margins inherent in large units operating at advanced steam conditions.

Boiler automatic control maintains the balance between fuel, air and water supply for a set output. In addition a sequence and inter-trip control is provided to prevent incorrect operation of auxiliaries, or to shut down the fuel supply in the event of dangerous conditions arising. The decrease in boiler temperature would cause severe stresses in the turbine, while sudden decrease in pressure might result in water carry-over with consequent damage to turbine blading. Automatic turbine unloading is therefore provided, and alarms are initiated if abnormal thermal expansion takes place. The standby auxiliaries on which the safety of the plant depends are arranged for automatic start-up, initiated electrically on failure of the main auxiliary or by an abnormal condition of pressure, water level or temperature.

The control and instrumentation of boiler and turbo-alternator units are centralised to allow for overall supervision by one operator who can thus make adjustments, if these are necessary, without delay. It has become the practice to centralise all controls of auxiliaries associated with starting, running and stopping of the entire unit in a separate ‘ plant ’ or ‘ unit ’ control room. For convenience and economy one room is provided for each pair of units and is located at or near the turbine floor level between these two units. In some cases provision for synchronising the generating units has also been included. This however complicates somewhat the arrangement and does not appear to be really necessary as synchronisation as well as loading of the unit can conveniently be carried out from the electrical control room.

The electrical control room thus accommodates equipment for unit load control and load despatch. The control of the main supply circuits for the auxiliaries is also carried out from this room. With this arrangement the dividing line of responsibility is clearly defined between the unit and electrical control room operators. For stations with one or two units and simple load distribution it is practicable to combine both control rooms into one, with consequent reduction in cost and the number of operators. The future trend may well be towards the single control room for large stations—a trend which is already reflected in nuclear stations.

Automatic switching of selected standby and emergency auxiliaries is necessary to prevent dangerous conditions arising on failure of running auxiliaries or on emergency shut-down of the plant. Sometimes automatic change-over of the entire unit auxiliaries to station supply is advocated. This however introduces a major problem. Due to the magnitude of inrush current in an induction motor at the initial time of circuit reclosure, it is necessary to introduce a time interval of a few seconds duration between the loss and reinstatement of supply. Tests carried out on motors indicate that shorter time intervals result in high inrush current which may exceed appreciably the motor stalling current. As a consequence the motor winding is subjected to severe mechanical stresses with resulting progressive damage and possible ultimate failure. On the other hand with delayed reclosing the motors run down practically to standstill and the kVA demand on restarting all auxiliaries simultaneously causes severe voltage-drops in the system. The supply system can, of course, be designed to cope with this condition, but at the cost of higher capacity and reduced overall efficiency.

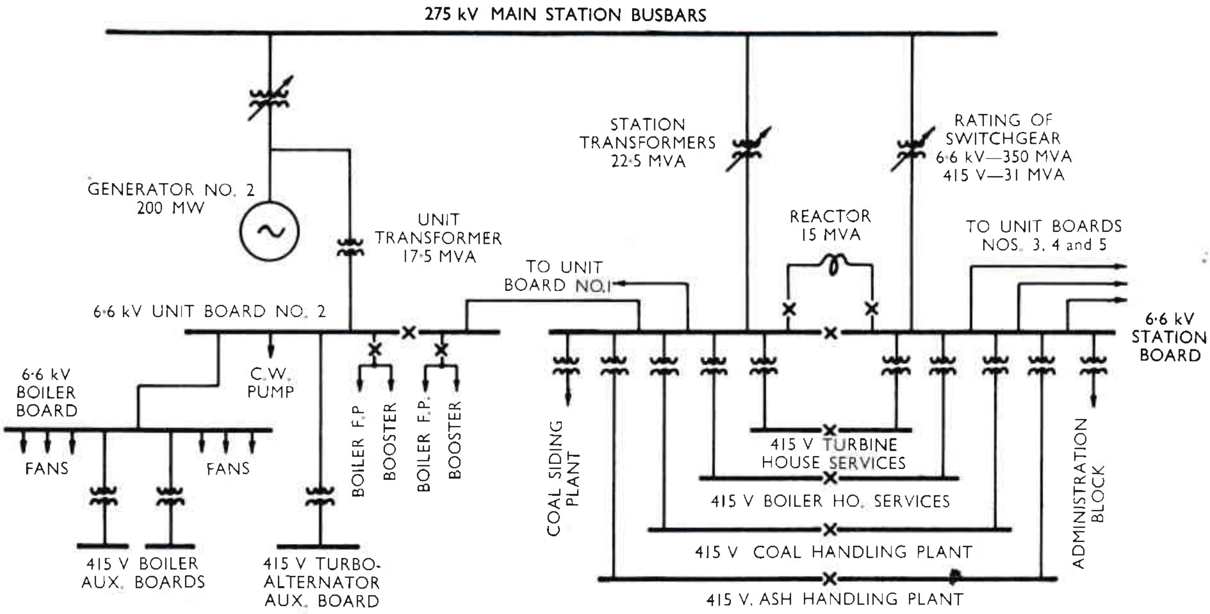

275 kV MAIN STATION BUSBARS
GENERATOR NO. 2 200 MW
UNIT TRANSFORMER 17·5 MVA
STATION TRANSFORMERS 22·5 MVA
RATING OF SWITCHGEAR 6·6 kV—350 MVA 415 V—31 MVA
REACTOR 15 MVA
TO UNIT BOARDS NOS. 3, 4 and 5
TO UNIT BOARD NO.1
6·6 kV UNIT BOARD NO. 2
6·6 kV STATION BOARD
6·6 kV BOILER BOARD
C.W. PUMP
FANS
FANS
BOILER F.P.
BOOSTER
BOILER F.P.
BOOSTER
COAL SIDING PLANT
415 V TURBINE HOUSE SERVICES
415 V BOILER HO. SERVICES
415 V COAL HANDLING PLANT
415 V. ASH HANDLING PLANT
ADMINISTRATION BLOCK
415 V BOILER AUX. BOARDS
415 V TURBO-ALTERNATOR AUX. BOARD

Fig. 14.—*Basic auxiliaries system for High Marnham* 5 × 200 *MW station*

Failure of the main supply is usually the result of a major fault, which should be investigated, and in these circumstances automatic change-over does not serve any useful purpose. Generally, the additional expenditure and complications involved in providing complete automatic change-over would not be justified for stations with large units.

Typical Arrangements of Auxiliaries Systems

The arrangement of the auxiliaries system is a matter of detailed consideration throughout the design of the station. Consequently, the type of drive, supply, distribution system, and layout have to be co-ordinated to obtain the best and most economic solution. All these factors must in turn be related to the conditions associated with a particular station, and it is therefore possible to refer only to a basic auxiliaries system.

Fig. 14 shows the basic auxiliaries system for a large station consisting of five 200 MW generating units. This station is now under construction in the United Kingdom and is designed to operate at 2,300 p.s.i.g., 1,050°F/1,000°F single reheat. The main and booster feed pumps are driven by squirrel cage motors rated 6,150 h.p. and 1,575 h.p. respectively.

As can be seen from the diagram, voltages of 6·6 kV and 415 V have been adopted. To allow for paralleling both station transformers without exceeding the 350 MVA fault level capacity of the switchgear, a reactor is inserted between the two sections of the station switchboard.

A typical arrangement of auxiliaries for a station consisting of four units of 275 MW is shown in Fig. 15. Electrically driven main boiler feed and booster pumps are assumed, having 50% duty capacity. For this station a three-voltage system appears to be convenient, and the maximum fault level at 11 kV is approximately 500 MVA when the two station transformers are in parallel and at the lowest tap-change position. All boiler pumps are connected to a double-busbar section of the unit board to allow convenient selection of any one pump as standby to be fed from the station supply.

A similar arrangement could be used for a station of 300 MW units, but above that size either 750 MVA breaking-capacity switchgear is necessary or the auxiliaries have to be sectionalised. It should be noted that with mechanically driven boiler feed pumps the unit auxiliaries load would be considerably reduced, but the station supply

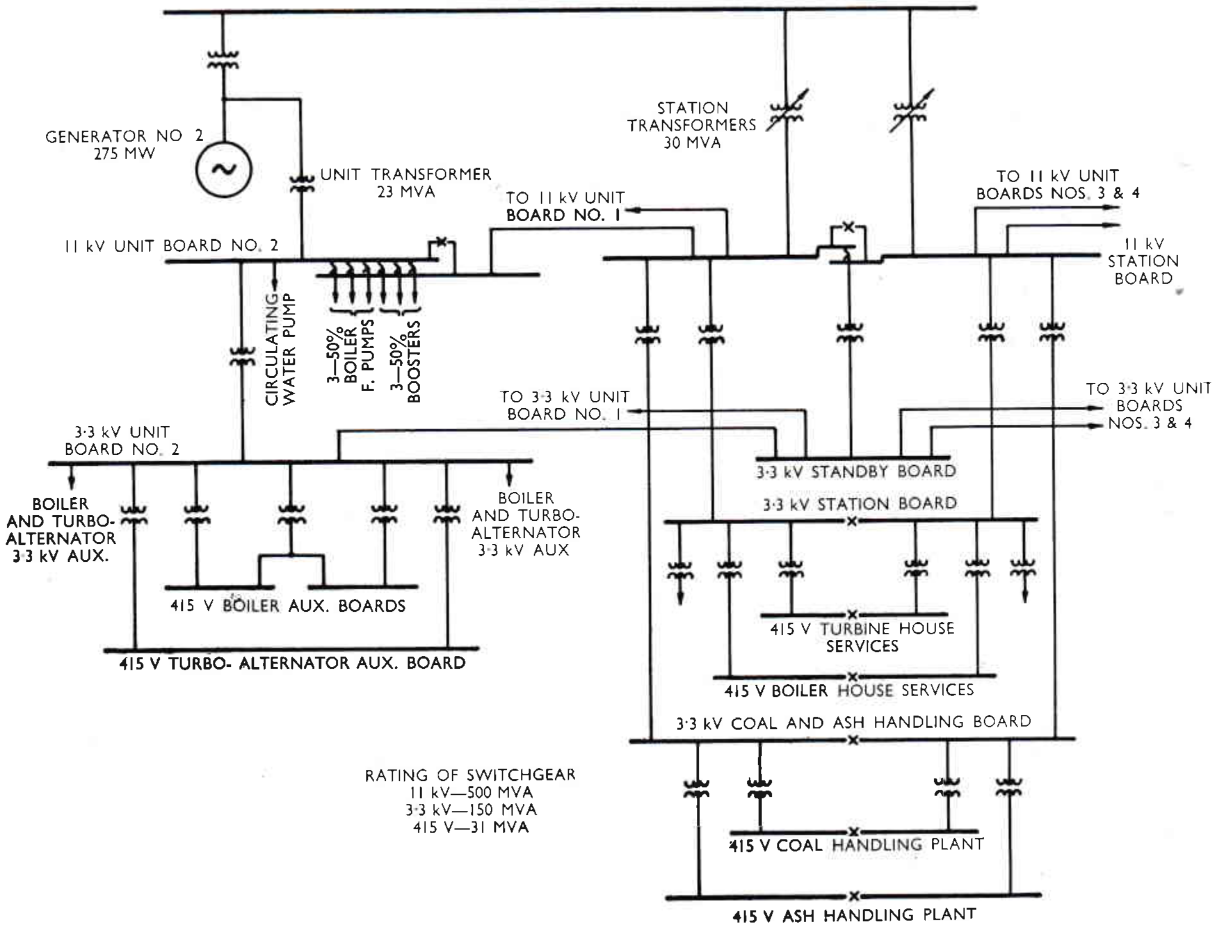


Fig. 15.—Typical auxiliaries system for a 4 × 275 MW station with electrically driven boiler feed pumps

capacity is not altered as this has to provide power for the standby feed pumps.

A preliminary arrangement for a station consisting of two 800 MW cross-compound type units operating at 2,300 p.s.i.g. has been investigated. One of the possible arrangements is shown in Fig. 16. It has been assumed that the main boiler feed pumps are not electrically driven. The capacity of each station transformer would allow replacing the load of only one unit transformer and at the same time supplying the standby feed pumps at full load. For a station consisting of 550 MW cross-compound units a similar arrangement could be used, and the fault level on the 11 kV switchgear would be reduced to 500 MVA.

In all the foregoing arrangements the main feed pump if electrically driven forms part of the main unit auxiliaries system. It may be of some advantage to separate the supply to these pumps and feed them at generator voltage, through reactors to reduce the fault level, as shown in Fig. 17. Motors of the size required could be manufactured for operation at 16·5 kV, which is the generating voltage for very large units.

NUCLEAR POWER STATIONS

Considerable progress has been made in nuclear power plant development over the last few years. The gas cooled reactor has been adopted in the United Kingdom for commercial application, while in the United States concentrated efforts are being made to develop the boiling water type reactor. In the gas cooled reactors the heat produced by the core containing fissionable uranium is removed by circulating CO_2. This heat is then passed through the heat exchangers, where steam is produced at the pressure and temperature required for the turbo-alternator plant. Fig. 18 shows the flow diagram for a typical 250 MW gas cooled reactor unit.

The steam conditions obtained at present are low, this being due to limitations imposed principally by the available material for canning the fuel. Further research and development is however being carried out and it appears likely that within the next few years very much higher steam conditions will be reached. Due to improvements in construction, further increases in output per reactor are within sight.

Auxiliaries

The problems associated with auxiliaries for nuclear stations differ in many ways from those for conventional steam plant. Firstly, a large amount of power is required for circulating the coolant through the reactor, and fine control of circulation is necessary within a wide range. Secondly, the emergency requirements necessitated by an uncontrolled shut-down of the plant are extremely stringent. This is primarily due to the ability of the reactor to generate delayed heat during a period after shut-down. A certain

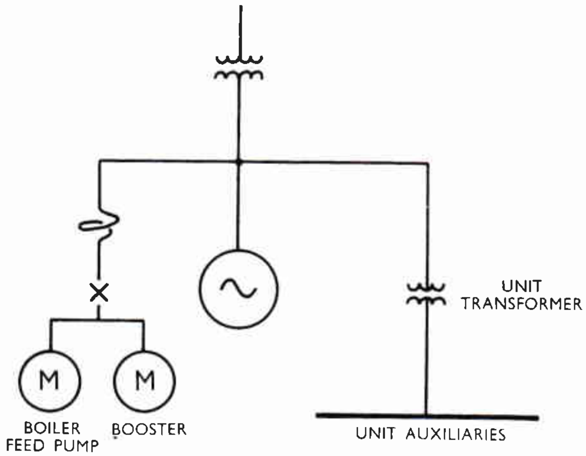


Fig. 17.—Arrangement for the supply of boiler feed pump motors direct from generator terminals

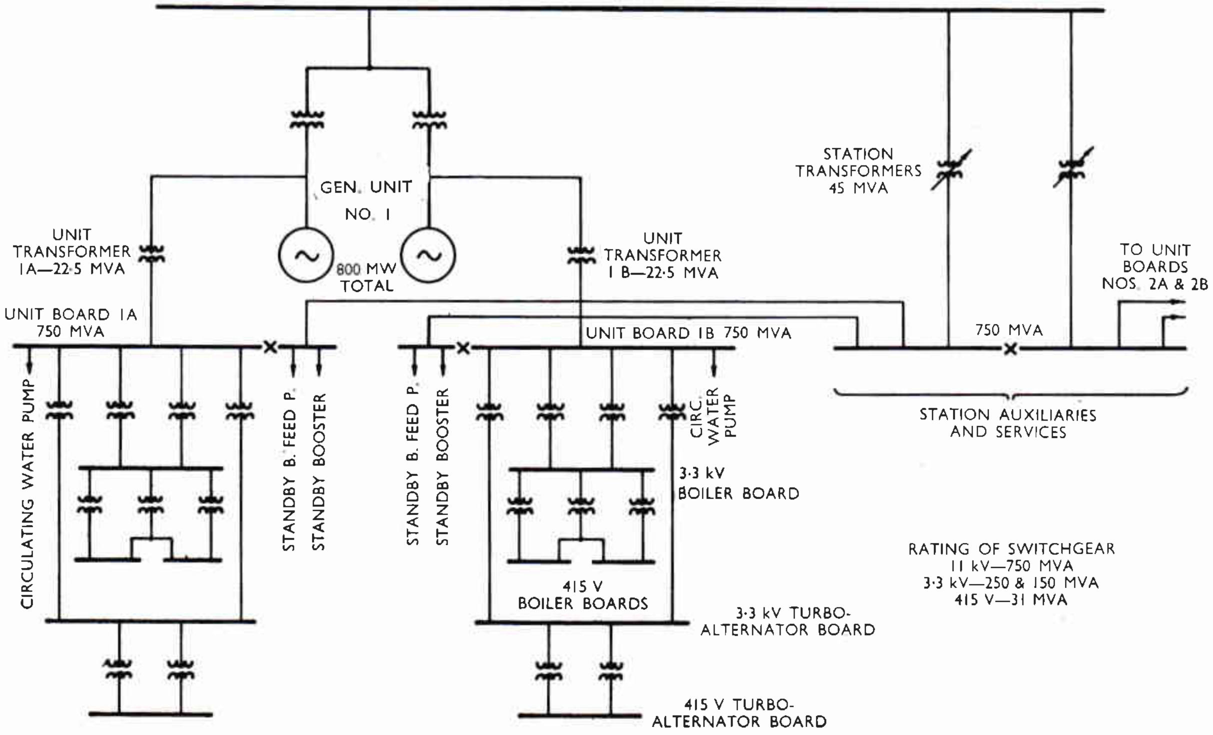


Fig. 16.—Typical auxiliaries system for a 2 × 800 MW station with non-electrically driven main boiler feed pump

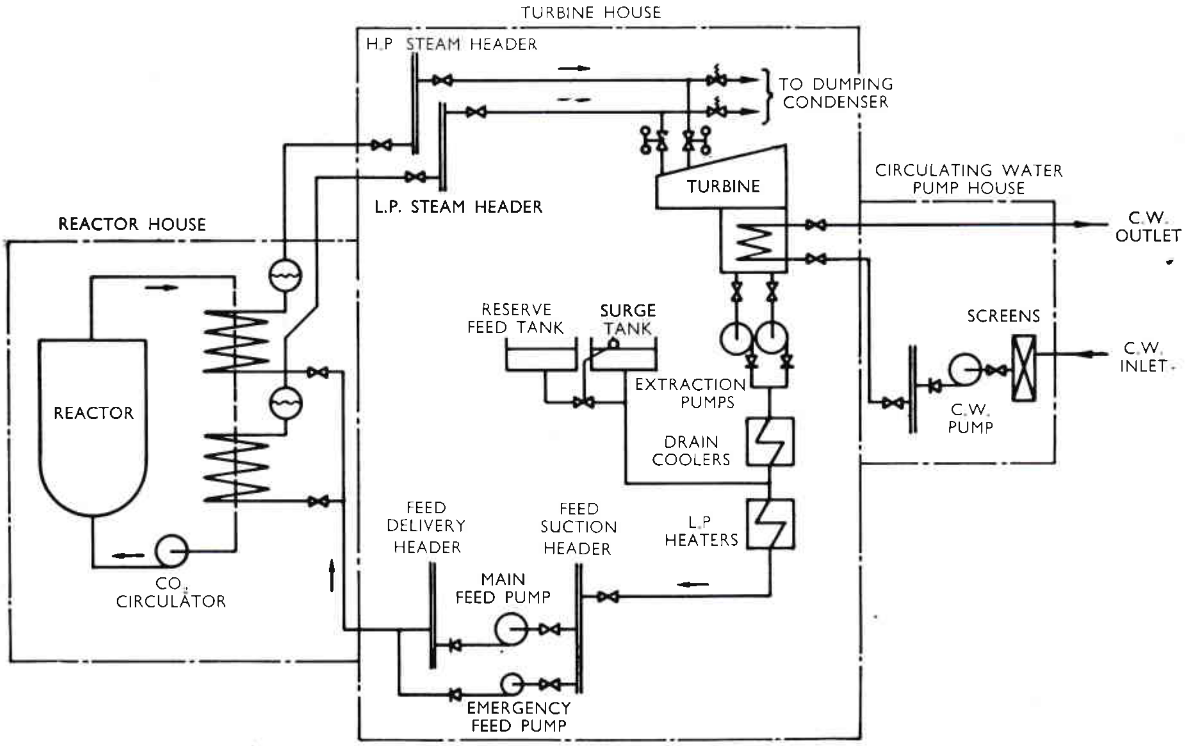


Fig. 18.—*Simplified flow diagram for a* 250 *MW gas cooled reactor unit*

amount of coolant must therefore remain in circulation to remove this heat. In addition, shield cooling and gas sealing as well as the supply to safety circuits must be maintained in service. The feed system must also remain operative, although only a small fraction of its normal flow is necessary to prevent excessive temperatures in the heat exchangers. It will be appreciated that all these essential auxiliaries must be available in the condition of emergency when the unit and station supplies may also be lost.

A further characteristic of nuclear reactors that has some bearing on auxiliary system design is that after a rapid shut-down the reactor cannot achieve full power again until many hours later, due to the build-up of ' poisoned ' elements which are normally kept at a suitably low level.

Detailed consideration of auxiliaries for nuclear plant is outside the scope of this article, and only main characteristics are briefly discussed in the foregoing paragraphs. The basic arrangement of an auxiliaries system for a typical 500 MW station consisting of two reactor units is shown in Fig. 19.

As can be seen from this diagram the unit system is applied to the reactor and three associated turbo-alternators. As for conventional stations the station supply is derived from the main busbars by two 100% duty transformers. This supply acts as standby to the normal unit supply as well as providing the necessary power for starting-up and for station services. A characteristic feature of the arrangement shown is the duplication of feeders to all switchboards associated with the reactor, as well as to all services. The emergency supply for the reactor essential auxiliaries is based on d.c. from batteries for the initial period of shut-down and is supplemented by diesel-generator sets which are started automatically on operation of the master trip relay.

The auxiliaries power demand for nuclear plant is high compared with that of a conventional high-pressure steam station. A typical figure for a two-reactor-unit station of 500 MW output is about 13% of power sent out ; of this almost 70% is absorbed by the gas circulators.

Thus the method of driving the gas circulators has a considerable influence on the design of the auxiliaries system. At Hinkley Point power station it was found that the best choice, taking into account overall economics and using current engineering practice, was an electric induction motor drive supplied from an 11 kV system separate from the other auxiliaries system and fed by steam driven variable-frequency turbo-generators.

The remainder of the normal running auxiliaries system of 50 cycles offered no problems, as no unusual quantities of power were involved, so that this is supplied from a conventional 3·3 kV and 415 V arrangement.

Present developments indicate that the gas circulators in future stations may be supplied from the main auxiliaries system. Under these conditions it may be necessary and even economic to use a three-voltage system to solve the electrical problems involved. The actual system for any particular case will depend largely on the number and size of the gas circulators ; these are tending to become larger and fewer in number per reactor.

Gas Circulators

The drives for gas circulators require most careful consideration. This is due to the large power involved, combined with a wide range of mass flow control necessary. In addition they must be able to provide a small amount of circula-

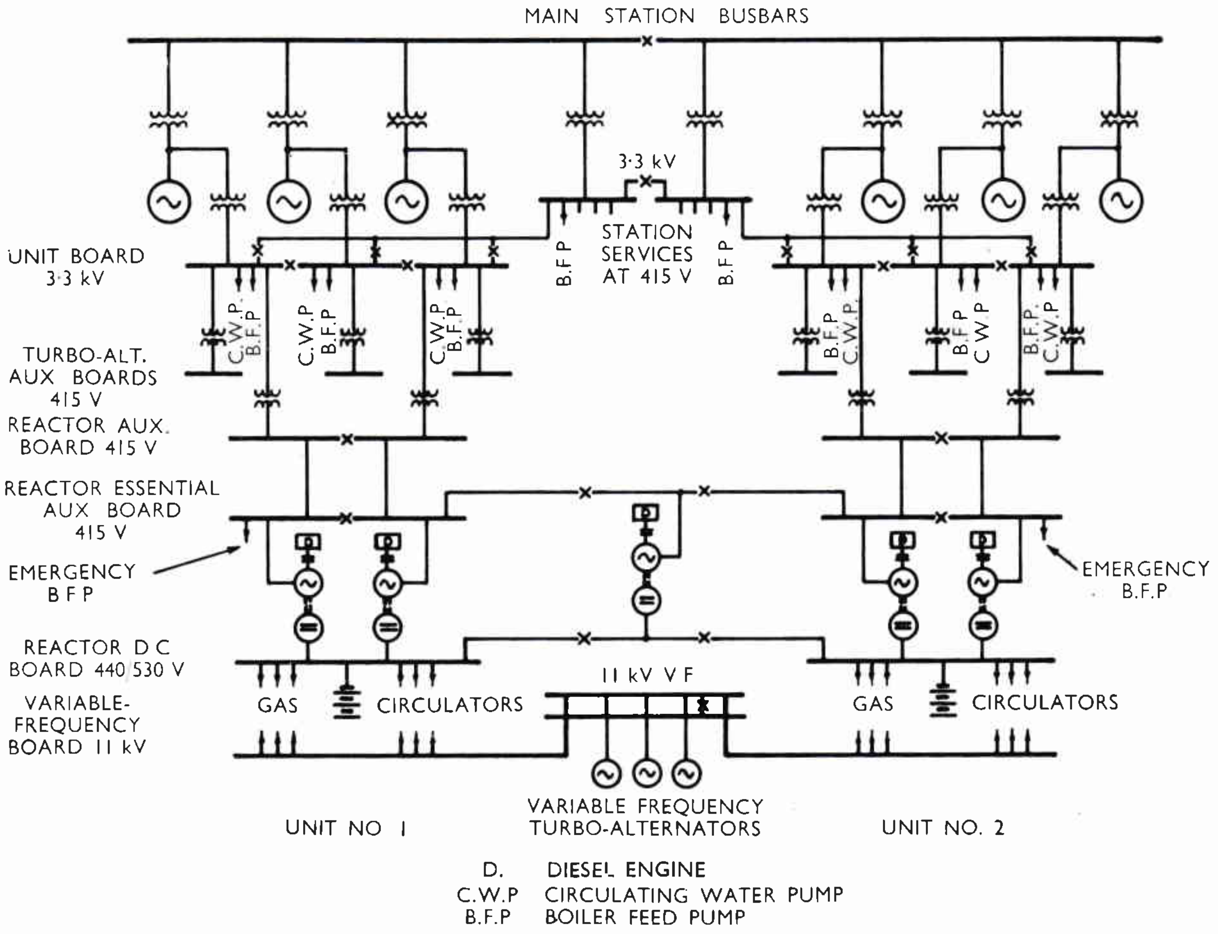

MAIN STATION BUSBARS
3·3 kV
STATION SERVICES AT 415 V
B.F.P
B.F.P
UNIT BOARD 3·3 kV
C.W.P
B.F.P
TURBO-ALT. AUX BOARDS 415 V
REACTOR AUX. BOARD 415 V
REACTOR ESSENTIAL AUX BOARD 415 V
EMERGENCY B F P
EMERGENCY B.F.P
REACTOR D C BOARD 440/530 V
VARIABLE-FREQUENCY BOARD 11 kV
D
GAS
CIRCULATORS
11 kV V F
VARIABLE FREQUENCY TURBO-ALTERNATORS
UNIT NO 1
UNIT NO. 2
D. DIESEL ENGINE
C.W.P CIRCULATING WATER PUMP
B.F.P BOILER FEED PUMP

Fig. 19.—Basic auxiliaries system for the first 500 MW nuclear power station, at Hinkley Point

tion under extreme emergency conditions, when the normal power supplies are lost.

From an economical and operational point of view, electric drive is probably the best choice. Effort is therefore concentrated on producing the most reliable and advantageous means of mass flow control in association with motor drives. A number of arrangements are possible, of which the following have been and are being considered:—

(1) Variable frequency generator supplying squirrel cage motors.

(2) Variable speed slipring motors with slip loss recovery or plain rotor resistor.

(3) Constant speed squirrel cage motors with the following possible means of obtaining mass flow control :

   (*a*) Gas bypass.

   (*b*) Circulator blade angle variation.

   (*c*) Hydraulic coupling.

The choice between these arrangements is influenced mainly by the capitalised running costs which are affected by the unit rating and load factor.

The auxiliaries supply arrangement is considerably affected by this choice ; for instance a variable frequency scheme obviously requires a separate system, and for slipring and squirrel cage motors in (2) and (3) the required high capacity of unit and station supplies creates problems of fault level and current rating.

Water Moderated Reactors

The problems of auxiliaries for water moderated reactors are very similar to those for gas cooled reactors. The total auxiliaries load demand is about 9% of the output for a 200 MW reactor unit. This is due to the smaller power requirements of the main coolant pumps compared with gas circulators. Additional problems with this type of reactor are created due to radio-active steam in the cycle. These problems are, however, mainly of a constructional nature.

AVAILABLE ELECTRICAL EQUIPMENT AND FUTURE TRENDS

The electrical equipment for power station auxiliaries incorporates special features, and The English Electric Company has developed switchgear, control gear, transformers, motors and actuators for this application.

High Voltage Switchgear

The trend towards air-break switchgear for auxiliaries systems started two decades ago. This type of gear is well established today and is likely to remain for a long time. It is well suited for power station application on account of the high degree of safety combined with suitable performance characteristics. The fire hazard is practically non-existent due to absence of oil, and fire fighting equipment can therefore be dispensed with. Maintenance requirements compare very favourably with those of the oil-type gear, and a high degree of availability is obtained. Furthermore, absence of current chopping reduces the over-voltages in the system and minimises outages due to insulation failures.

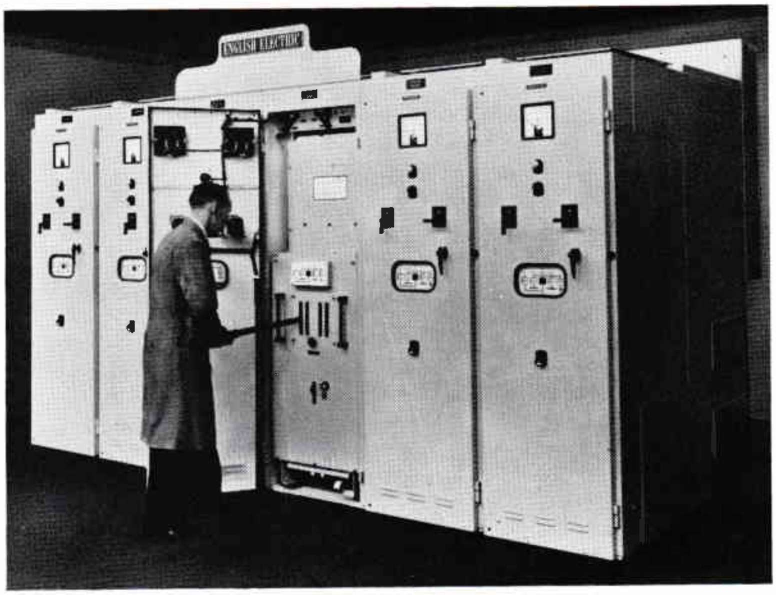


Fig. 20.—Class 'E' 3·3 kV 150 MVA switchboard, showing manual emergency operation of one circuit-breaker

For the higher voltages of 3·3 kV, 6·6 kV and 11 kV, the Class 'E' range of air-break switchgear is available. This has been developed specifically to meet the requirements of modern power stations, and embodies all necessary interlocks to ensure completely safe operation. The truck mounted circuit-breakers are of the shunt-trip medium-speed type with a total opening time of approximately 5 cycles, which is satisfactory for protection of the equipment and for maintenance of system stability under fault conditions. Solenoid operation from the battery is usually provided, being most suitable for power station application.

The stationary portion is of sheet steel construction and incorporates single or duplicate busbars within the same standard dimensions, cable terminations, instrument transformers, and panels for mounting a limited number of instruments and relays. On-load busbar selection can be provided.

The range of air-break switchgear available or under development is given in Table III, and a typical switchboard is shown in Fig. 20.

Low Voltage Switchgear

For low voltage auxiliaries air-break switchgear is most suitable, for similar reasons to those given for the high voltage gear. Generally, for the main feeders and interconnectors, circuit-breakers are provided, while for outgoing circuits a combination of switch and high rupturing capacity fuse is satisfactory. Motor circuits incorporate in addition contactors with thermal motor protection. The 'Superform' distribution equipment developed by The English Electric Company incorporates all these features together with safety interlocks and ease of maintenance (Figs. 21 and 22).

The present practice is generally to limit the rating of 415 V motors to about 150 h.p. For the larger stations however the tendency is to increase this limit on account of the reduced cost of switchgear and motors, and probably a limit of about 200-250 h.p. would be more economical. Special consideration has to be given to motors in remote locations.

An increase of voltage to 550 V would no doubt ease many problems associated with current ratings and fault level, while involving no extra cost for the motors and switchgear. At the same time reduction in cable cost and copper losses would be quite significant.

The available ratings of the OB22-24 air circuit-breakers which are built into the 'Superform'

TABLE III

RANGE OF AIR-BREAK AIR-INSULATED SWITCHGEAR AVAILABLE

Type	Voltage kV	Current up to : amperes	Fault Rating MVA	Busbars SB—single DB—double
OB22	Up to 0·66	800	25 at 415 V	SB
OB23	Up to 0·66	1,600	31 at 415 V	SB
OB24*	Up to 0·66	3,000	31 at 415 V	SB
OB33L	3·3	2,000	150	SB
Class E3	3·3	2,000	150	SB or DB
Class E4/E5 . .	3·3	2,000	250	SB or DB
Class E5	6·6	2,000	250/350	SB or DB
Class E6	6·6	3,000	350	SB or DB
Class E7	11	2,000	500	SB or DB
(Projected)	11	2,000	750	SB or DB

* Under development.

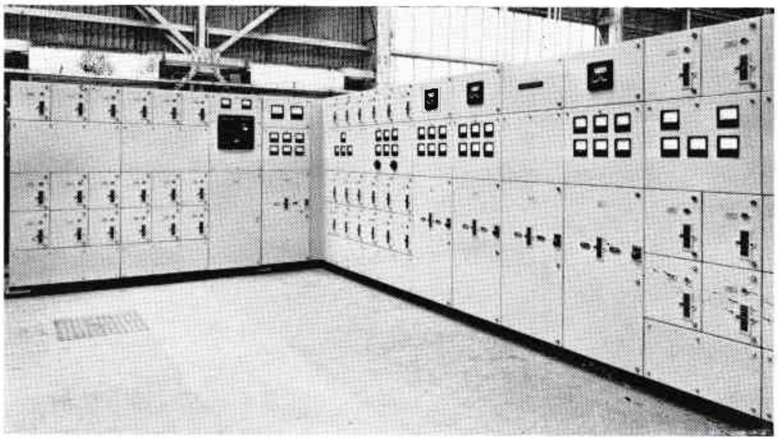


Fig. 21.—Part of a station auxiliary switchboard of 'Superform' construction, comprising OB23 air circuit-breakers, fuse-switch units, instruments and meters

equipment are shown on Table III. The fuse-switches are available up to 750 A for on-load isolation, and above that, for off-load isolation, the ratings extend to 1,200 A for the fuses and 2,000 A for the switches. For motor circuits, contactors can be incorporated in the switchboard in combination with the fuse-switch units. The fuses are of the high rupturing capacity cartridge type and are suitable for use on systems having a fault level of 35 MVA at 415 V.

Solenoid operation is usually provided on all main feeder and interconnector circuit-breakers to allow for remote operation from the control room. The other feeders can be manually operated. Two distinct types of contactors are available—the electrically held-in and the latched-in types. The former type if a.c. operated is sensitive to supply voltage dips, and consequently d.c. operation from the station battery is generally preferred although with the disadvantage of the additional drain on the battery which may be quite high for a large station. The latched-in type has neither of these disadvantages, but is larger and requires more maintenance due to more complicated closing mechanism. For motors larger than 150 h.p. it is preferable to provide circuit-breakers instead of contactors.

It has become a frequent practice to centralise the low voltage switchgear together with the motor controls in complete switchboards which are located at convenient points within the power station. With this arrangement means of isolation, or at least of locking out the circuit at the motor, are desirable for safety. Another approach is centralisation of distribution with fuse protection and isolation, with the contactors located at the motors. In this case the switchboards incorporate outgoing fuse-switch combinations while the contactors are built into self-contained starters complete with incoming isolators. In either case the contactors are controlled from the remote control panels in addition to local control.

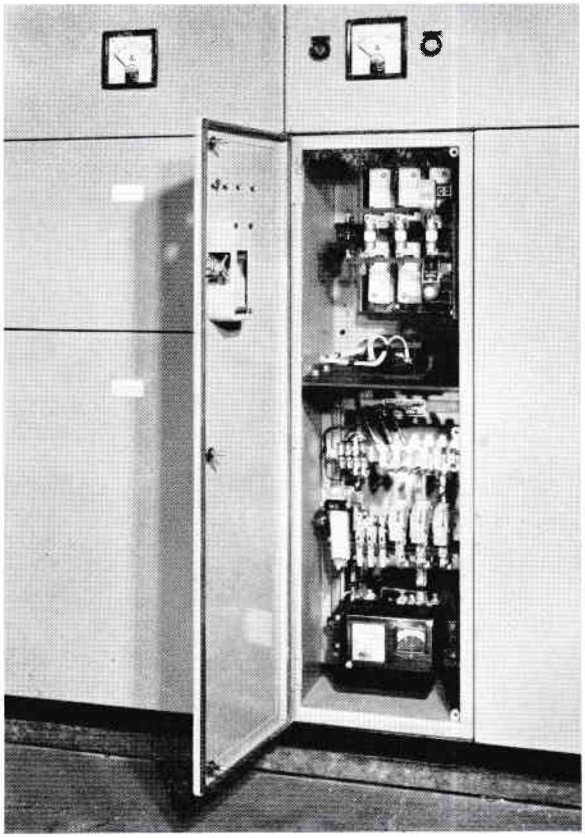


Fig. 22.—Compartment of switchboard accommodating 'Superform' fuse-switch and contactor

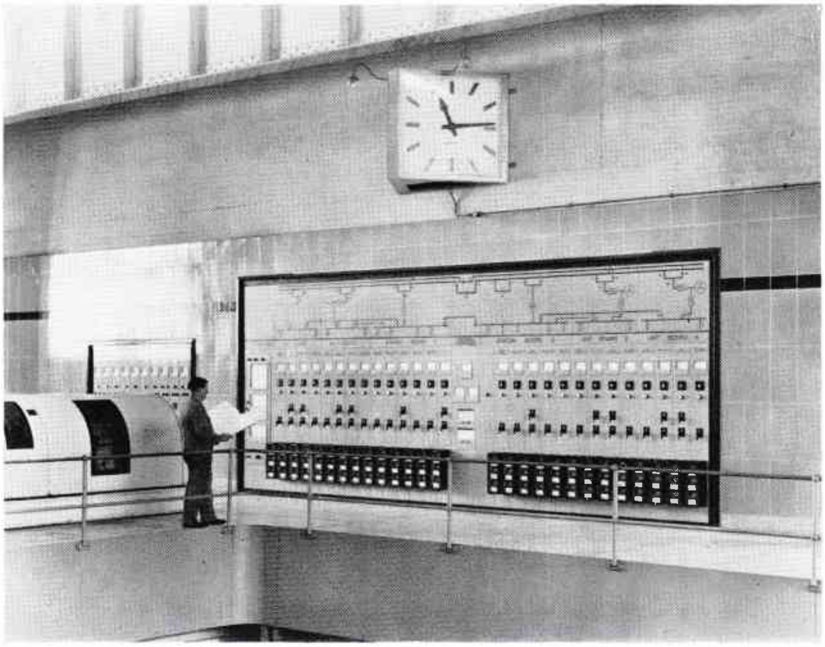


Fig. 23.
Power station auxiliaries control board

Control Gear

Auxiliaries control is centralised in appropriate panels or desks in accordance with functional requirements. Switching control is however also provided at the switchboards for maintenance purposes. Mimic diagrams are very helpful on control panels, with instruments and controls built into the diagram. This arrangement however should be used with discretion, particularly on plant control panels, as otherwise dislocation of instruments reduces the ability of the operator to follow the operation of the plant. Indicating lights and visual alarms arranged for 'dark' operation under normal conditions are preferable to avoid a constant multitude of lights, which is distracting. The English Electric Company manufactures various types of control boards and desks, built on the 'unitised' principle which allows for extensions or modifications to be easily carried out.

Transformers

Transformers for power station application are of standard design and of the oil insulated type. Natural circulation cooling is preferable for unit transformers due to absence of cooling fans and pumps and thus increased reliability. For station transformers of the larger ratings, above 15-20 MVA, mixed natural and forced cooling or water cooling is justified on account of lower cost and low load factor, but against these lower costs must be set the additional cost of providing the auxiliary

Fig. 24.—*Wall mounted pattern control panel*

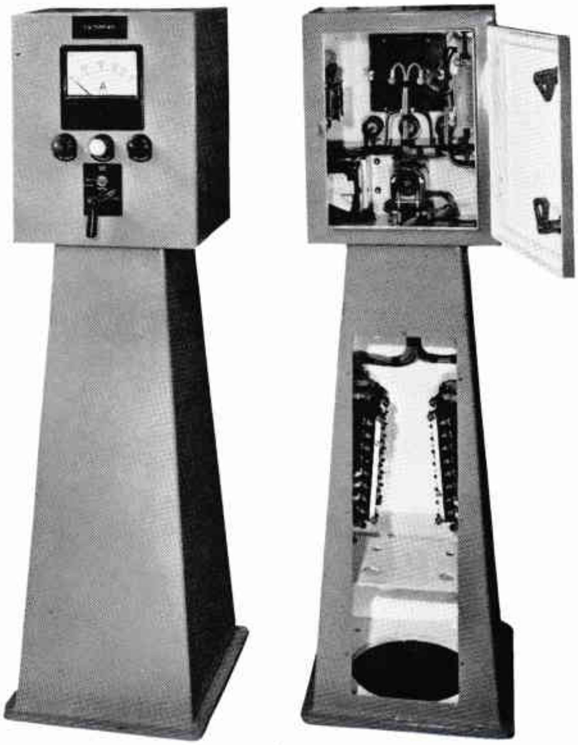


Fig. 25.—Front and rear views of floor mounted pedestal type control box

supply, cables and control gear, and of course the capitalised cost of the power used. In addition, in the case of the water cooled alternatives, there is the added cost of providing the water connection, means of circulating the water, and either the volume of water or means of cooling the water.

The relation of the cost of various types of cooling to that of natural cooling is indicated in Table IV. The values are approximate only, and applicable to voltages up to say 132 kV. At higher voltages the differences would be reduced due to the larger part of the total cost being represented by the basic transformer. In respect to the OFW cooling the factors allow only for 100% cooling without standby.

Water cooling has the attraction of reduced space requirements but unless dictated by other considerations the use of water should be avoided so as to preclude the possibility, however remote, of water getting into the oil, with consequent damaging effect on the transformer insulation.

The ratio between copper and iron losses is of importance and should be selected in accordance with the duty of the transformer. The unit transformer operates at about 75% full load when the generator unit is operating under normal conditions at full load. On the other hand the load of the station transformer under normal conditions is about 20-30% of its rating, and it is working near full load only for short periods during starting or emergency conditions. Fig. 26 shows the most efficient loadings at various transformer copper/iron loss ratios.

It may therefore be advantageous in some instances to reduce the iron losses in combination with increased copper losses for the station main and auxiliary transformers.

When selecting the transformer reactance, consideration should be given to values obtainable

TABLE IV

APPROXIMATE COST RELATIONSHIP OF TRANSFORMER COOLING METHODS

MVA	O.N.	O.N./O.F.B.	O.F.W.
7·5	100	102	92
10	100	98	88
15	100	95	85
20	100	92	82
30	100	90	80
45	100	88	77
60	100	87	76
75	100	86	75

O.N. Oil immersed, naturally cooled.

O.F.B. Oil immersed, forced oil circulation and air-blast cooled.

O.F.W. Oil immersed, forced oil circulation and water cooled.

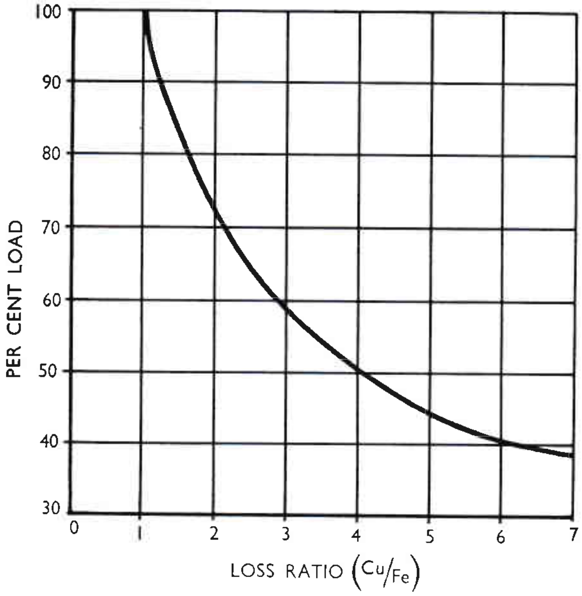


Fig. 26.—*Most efficient transformer loading in relation to copper/iron losses*

from a standard design. Higher or lower values can be obtained but may involve increased cost, and when high circuit reactance values are required consideration should be given to separate reactors. Typical average values of transformer reactance are given in Fig. 27.

Motors

The power station auxiliary motors range in size from fractional horse-power used for the control of valves to several thousand horse-power for driving the boiler feed pumps. Although the majority of these motors are of the squirrel cage type, their characteristics vary considerably and different types of enclosures are necessary to meet the operating conditions.

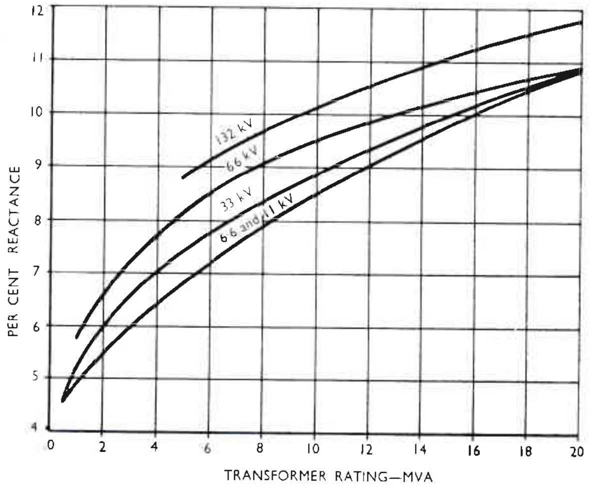


Fig. 27.—*Typical average values of transformer reactance*

Quick starting is required, particularly for the standby auxiliaries, and with squirrel cage motors this is obtained by direct-on-line starting. The simplicity of the switching and control equipment for this type of motor together with its inherent reliability are assets which are relinquished only reluctantly for other types of drives. The specifications of the British Central Electricity Generating Board allow a starting current of 6 times full load for auxiliary motors associated with boilers, except those for the circulating water and boiler feed pumps for which the requirement is $4\frac{1}{2}$ times full load.

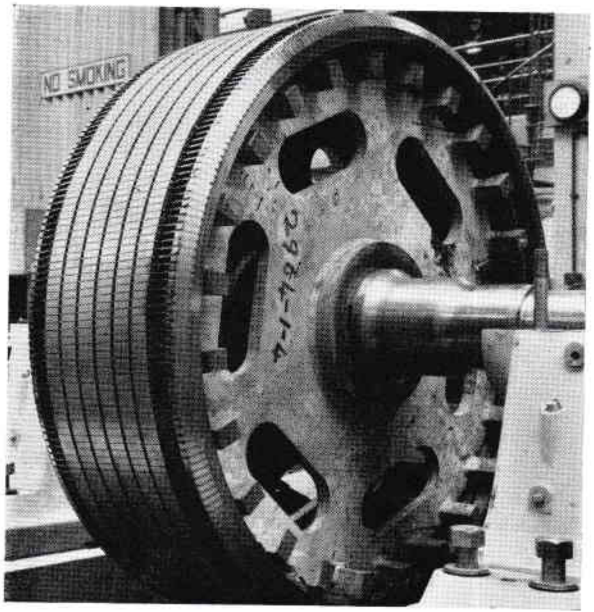


Fig. 28.—*Squirrel cage rotor of* 970 *h.p.* 297 *r.p.m. motor for circulating water pump*

For drives requiring variation of speed, slipring motors can be used. The starting current for these will be below twice full load and on pump drives about full load. Stable speed variation

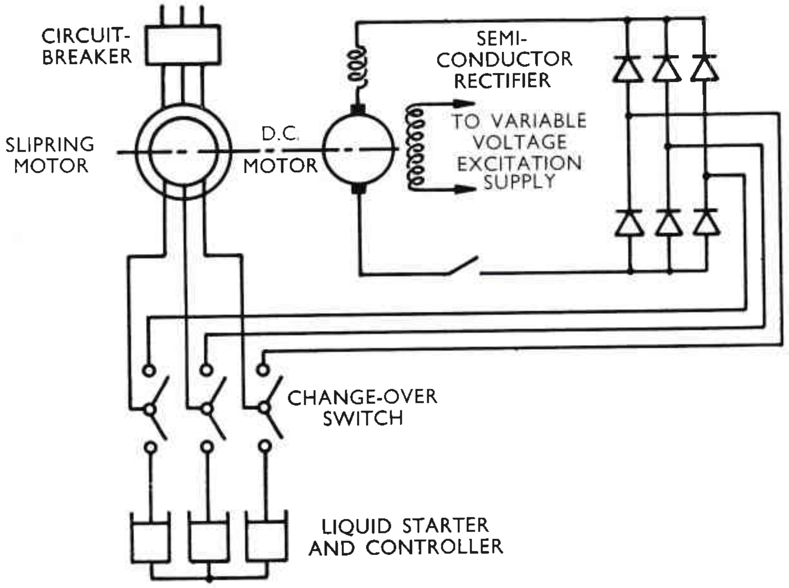


Fig. 29.—Typical arrangement for slip losses recovery

down to 50% can be obtained. These motors are now available for speeds of 3,000-3,600 r.p.m. and can therefore be applied to boiler feed pumps.

Unfortunately the efficiency of the straight slipring motor when operating at much reduced speed is low, as losses cannot be recovered from the rotor regulating resistor. Development has recently been completed however which would allow recovery of the larger part of these losses. A typical slip-losses recovery arrangement is shown diagrammatically in Fig. 29.

The extra cost of the conversion equipment may be justified, depending on the load factor, by the saving in recovered rotor slip energy capitalised over a period of its useful life. The efficiency of this type of equipment is approximately constant over the speed range at a value between 1 and 2% less than the normal full load efficiency of a slipring motor alone. This is likely to restrict economically the application to larger drives intended to operate for long periods at reduced speed. For application to feed pumps a separate d.c./a.c. motor-generator set is required, as due to the high speed of the pump it is not practicable to mount the d.c. machine on the main motor shaft.

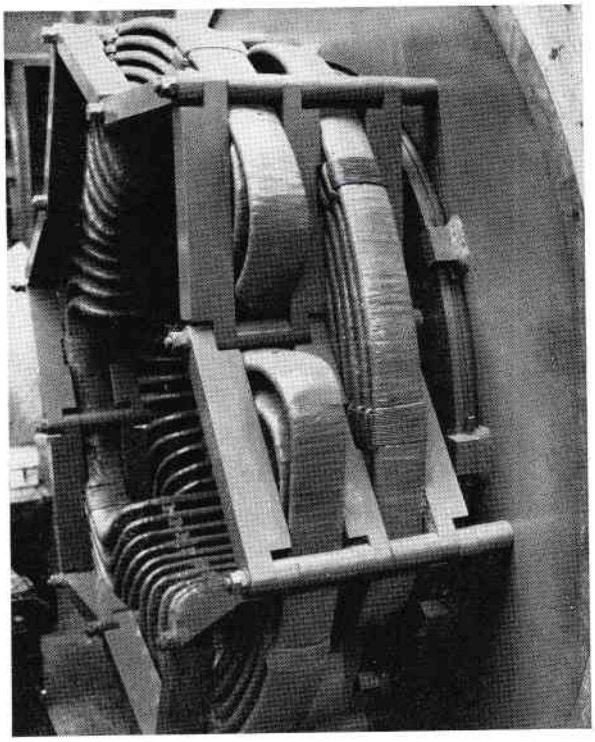


Fig. 30.—Overhang of stator winding of typical high-speed motor, showing method of clamping to withstand stresses due to direct-on-line starting

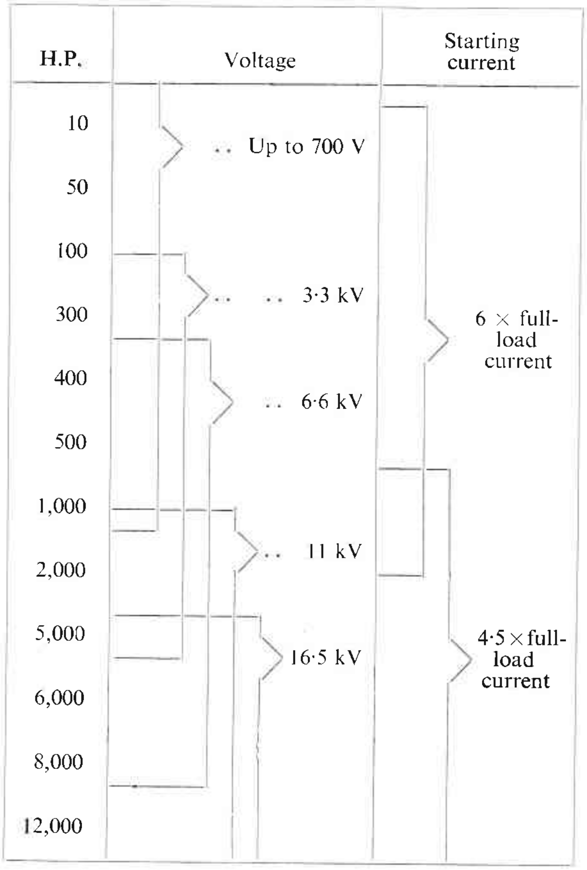
Voltage

Operating voltage in relation to rating of the motor is limited by considerations of design and manufacture, and a typical range is given in Table V. In general the higher the voltage of the motor the higher will be its cost, and as the lower voltage windings have a larger copper section they are better able to withstand the stresses imposed by direct-on-line starting.

If therefore a higher voltage is necessary to supply a small motor due to its remote location, it is more satisfactory to use a step down transformer solidly connected to the motor terminals and mounted near the motor.

TABLE V

TYPICAL VOLTAGE AND STARTING CURRENT RANGES FOR A.C. MOTORS



Voltage variations of ±5% and frequency variations of ±4% are met without difficulties. Variations over a wider range can be met by providing a larger motor, at an additional cost. As previously mentioned the motors are also designed to operate for a period of 10 minutes at a voltage reduced to 75% of nominal. Voltage dips of greater magnitude but of a transient character of 0·2-0·3 seconds likely to occur during system faults do not affect the operation of the motors.

Insulation

The selection of the type of insulation for auxiliaries motors is based on either Class 'A' or 'B' as defined in British Standard 2757. Other materials such as Class 'E' and 'H' are not normally used, as other design considerations such as maximum torque tend to determine the motor frame size and so limit the temperature rise. Class 'A' insulation is preferable for all small and medium size motors up to about 300 h.p. Above this rating, as well as for voltages from 6·6 kV onwards, Class 'B' insulation is considered more satisfactory. The higher temperature rise allowed for Class 'B' tends to result in smaller motors than with Class 'A'.

Enclosures

Selection of enclosures is based on the desired degree of protection for the motors, and this depends on the conditions existing in a particular location. Generally, drip-proof enclosures are satisfactory for indoor use when conditions are reasonably clean. Recourse to a more expensive enclosure should be made only when operating conditions are likely to justify this.

Specific problems are associated with some motors and these require individual consideration. With high speed motors of large output, as for example for boiler feed pumps, the windage noise level is high. To reduce this a totally enclosed motor is provided, with closed air circuit and either air or water cooled. A cheaper arrangement is obtained if a drip-proof motor is fitted with a special air inlet and outlet to reduce the windage noise to a reasonably low level.

Totally enclosed motors in the smaller sizes are usually fan cooled, although plain totally enclosed types are often used for short-time-rated drives as for cranes. Medium and large sizes have a closed air circuit, the air being passed through a cooler which is built either inside or outside the motor frame. These coolers can be either air cooled or water cooled. Air cooled motors are built in all sizes up to about 1,500 h.p. at any speed, but at outputs above 500-600 h.p. it becomes more economical to use water cooling.

For outdoor use weatherproof type enclosures are necessary. These can be provided readily on totally enclosed motors by suitable sealing of joints and provision for breathing. In outdoor areas reasonably free of coal dust a cheaper arrangement can be provided, usually referred to as 'ventilated weather protected'. This is basically a splash-proof open ventilated type but special provision is made in the air inlets and outlets to ensure that little moisture or water vapour is carried within the motor. Special attention is paid to the sealing of the windings, and heaters are provided for switching on when the motor is stationary. The application of this type of enclosure is usually limited to the motors of the larger auxiliaries such as boiler fans and circulating water pumps which may be located outdoors.

Cables

Cabling, being part of the auxiliaries installation, should receive careful attention. The size of cables is determined by the maximum continuous load current. Factors influencing the heat dissipation should be taken into account, and these are : the method of laying, proximity of other cables and ambient temperature. Furthermore, consideration should be given to short-circuit rating for the smaller sizes as well as voltage drop for long lengths to remote plant. Table VI gives the recommended minimum cable sizes for various short-circuit conditions based on a fault duration of 0·3 second. These sizes can be reduced for cables protected by high rupturing capacity fuses.

TABLE VI

RECOMMENDED MINIMUM CABLE SIZES IN SQUARE INCHES FOR SHORT-CIRCUIT CONDITIONS OF 0·3 SECOND DURATION

Fault MVA	System Voltage—kV			
	0·415	3·3	6·6	11
15	0·2	—	—	—
25	0·4	—	—	—
30	0·4	—	—	—
40	0·6	0·1	—	—
150	—	0·25	0·15	0·1
250	—	0·4	0·2	0·15
350	—	—	0·3	0·2
500	—	—	0·4	0·25
750	—	—	0·6	0·4

For power cables the paper insulated lead sheathed type is generally used. Three-core cables are satisfactory up to about 0·5 sq in. conductor size and these are generally armoured. For larger sizes single-core unarmoured cables are preferable on account of handling during erection and improved rating. Armouring is desirable on all three-core cables to reduce their vulnerability to mechanical damage. The armouring is usually left bright for indoor installation, but sometimes fire-resisting serving is provided in fire-risk locations. Serving is provided for cables laid direct in the ground.

Special consideration should be given to the routes of unarmoured cables within the power house, and provision of underground tunnels or covered concrete trenches is desirable to reduce the likelihood of mechanical damage.

For small loads up to about 30 h.p. mineral insulated cables are often used due to the ease and economy in installation. This type of cable can operate in high temperatures and is very robust mechanically.

Covered trenches and ducts should be included in the civil construction to afford obstructionless cable runs in basements of boiler and turbine houses. Under operating floors and on upper levels, cables are run on prefabricated sheet metal racks. The type of fixing employed should facilitate ease of erection of cables in any desired order and also allow for probable future addition or removal.

Careful planning at an early stage of power station design is necessary to ensure good results from the engineering and aesthetic points of view.

CONCLUSIONS

The trend towards large generating units of 200 MW and above operating at advanced steam conditions is now well established. For very large

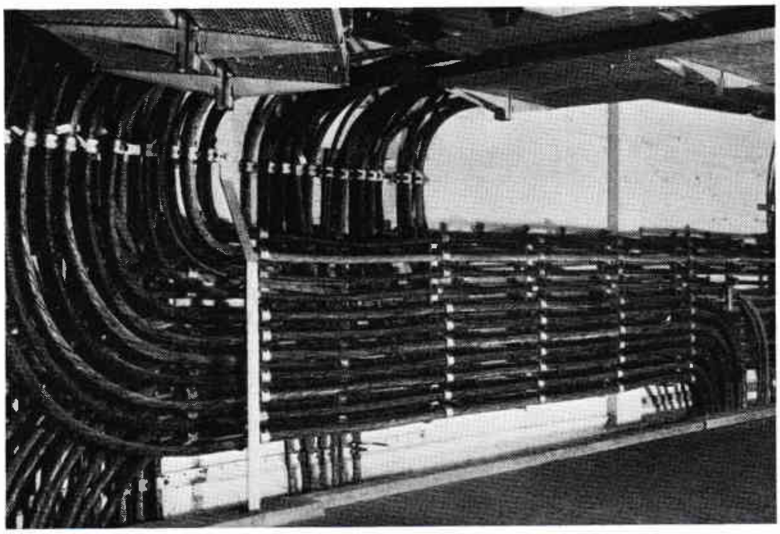


Fig. 31.—Typical arrangement of cabling in power station

Photograph by courtesy of British Insulated Callender's Construction Company Ltd.

interconnected systems the general level may be established in the near future at about 400 MW unit size with the largest sets approaching 800 MW.

The steam conditions are likely to level at 2,300 p.s.i.g., 1,050/1,050°F single reheat, although development in the supercritical range with double reheat cycle is well advanced.

In the field of nuclear stations the steam conditions obtained at present are low. Intensive research and development are however being carried out and it appears likely that within the next few years much higher steam conditions will be reached, resulting in higher efficiency and increased output per reactor.

Electric drives for all auxiliaries are now generally accepted for conventional as well as nuclear stations, with special attention being given to boiler feed pumps and coolant circulators for reactors. Consideration is also being given to means of driving the boiler feed pumps from the main generator shaft or by a separate turbine. The arrangement to be adopted is of course dependent on economical considerations and on the development of reliable electrical drives with speed control.

The unit auxiliaries system can be advantageously extended to the largest generating units now envisaged. Sectionalisation of auxiliaries supply is justified for cross-compound units, but with tandem units a straight unit system is preferable due to its simplicity, even at a cost of increased short-circuit rating of switchgear.

The auxiliaries load associated with very large units above 200 MW cannot be conveniently accommodated on a two-voltage auxiliaries system, and a three-voltage system, such as 11 kV, 3·3 kV and L.V., provides a solution.

The equipment at present available or under development can meet the requirements for auxiliaries for the largest generating units contemplated. Further development is necessary however in electrical drives with economical speed control for large boiler feed pumps for conventional steam stations and coolant circulators for nuclear stations.

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